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THE MICROSCOPIC STRUCTURE OF IRON AND STEEL.

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LADIES AND GENTLEMEN:—The subject which I am about to bring to your attention to-night, is one of the most interesting developments, which the science of metallurgy has ever made, and although the use of the microscope in the practical metallurgy of iron and steel is yet but in an experimental stage, it promises to increase our knowledge of the properties of metals to a degree that it would be difficult to approximate. Although the ultimate practical value of this subject has been much questioned, one thing is absolutely certain—that with the microscope, we can see vastly more of the structure of the metal than could be seen with the naked eye. We see many things, the existence of which we never before suspected, and, as in the case of the application of chemistry to this same branch of engineering, it is only required that the data so derived should be properly interpreted and applied,

that their practical value may be correctly understood. It has long been a custom amongst persons engaged in the manufacturing of iron and steel, to fracture portions of their product and to examine the fresh surface with a magnifying-glass, or more frequently with the naked eye only, by this means forming some idea of the quality of the metal. These tests were still further elaborated by having the metal surface ground down and etched, and if the etching was very deep, to have prints made from it on paper. Such tests were of course very crude, and at the best, gave only questionable information, as it is sometimes the case that two different pieces of iron or steel, which appear exactly alike to the naked eye, or under a low magnification, will have very different physical properties. It is certainly true, however, that an experienced man can usually judge very correctly the value of a metal by its fracture, but unfortunately such is not always the case, and it is in these instances that the microscope is of value. The study of the microscopic structure of metals, as a scientific pursuit, is a comparatively new one; indeed, this is the first time a lecture has ever been delivered upon it in this country. In view of this circumstance, it might be well to glance at the literature on the subject, that some idea may be formed of the amount of work already done.

Probably the first authenticated publication on the subject was a paper read by Herr Martens, before the Verein zur Beförderung des Gewerbfleisses, of Berlin, about the year 1880. This paper is mostly a description of a number of specimens of iron and steel, the fractured surfaces of spiegeleisen and glass, and of crystallized spiegeleisen, etc. The magnification does not appear to be great, nor do the specimens selected illustrate typical cases. Since that time, Martens has done a large amount of excellent work, which has been published in a number of German journals. After Martens, Dr. H. C. Sorby, of Sheffield, Eng., took up the subject, and embodied his first work in a lecture on the "Microscopical Structure of Iron and Steel." In 1883, this lecture was elaborated by Mr. J. C. Bayles, of New York, and published in a paper in the *Transactions of the American Institute of Mining Engineers.** Owing to the novelty of the subject, and a desire to have it taken up by engineers in this country, he very properly made the paper mostly a description of the methods of preparing and etching the

* Vol. xi, p. 261.

metal, and the proper selection and use of the microscope. A great stimulus has recently been given the subject by the exertions and publications of the well-known metallurgist, Dr. Hermann Wedding, of Berlin, through whose influence a special department has been established for this work at the Royal Experimental Station, in Berlin. During the last two years, a considerable number of papers have appeared in this country and in Europe, and although, like every new branch of scientific research, it has to fight its way before its usefulness is recognized, we have reason to believe that before a great while it will be firmly established as a branch of the metallurgy of iron and steel. As we have just seen, the use of the microscope in studying the structures of metals, is of very recent date. This is probably due to the ignorance of the uses of the microscope amongst metallurgists, and to the mechanical and optical difficulties which stood in the way; besides, as you well know, it has only been within recent years that any science at all has been applied to the manufacture of iron and steel. The mechanical and optical difficulties have, in great measure, been overcome, and since the successful application of photography to microscopical work, little else remains to be desired, except better facilities for the use of high powers and a greater perfection in the preparation of the specimens to be investigated. The use of photography has been an enormous help, as it enables a rapid and accurate registration—so to speak—to be made, of what is seen under the microscope, and with a very small expenditure of time and labor, as is not the case when drawings are made.

One of the aims of this lecture is to interest people sufficiently to take up the subject themselves; it might, therefore, be well before going further, to give a short description of the methods used in preparing the specimens, and the tools ordinarily required for the same.

These tools, under ordinary circumstances, are few in number, quite simple and cheap. The following list will be found to contain about all required, unless very fine and accurate work is desired, in which case, the number and cost of same can be increased indefinitely.

One-half dozen large, coarse files.
One hack-saw, with extra blades.
One-half dozen small drills.

One table-vise.
Several hammers.
Several cold-chisels.
Two pairs of fine steel forceps.
Thick glass-plate (hard-glass).
Three sizes of fine emery (70, 80, 90).
Two whet-stones (fine quality).
One gross of small glass phials.
Paper-labels for same.
Stick of sealing-wax.
Spirit-lamp.
One-half gallon kerosene.
Nest of small beakers.
Wash-bottle.
Evaporating dish (porcelain).
One dozen watch-glasses.

Although a complete chemical laboratory might be used to great advantage, the number and quantity of chemicals actually necessary is very small indeed; hydrochloric, nitric, and acetic acids, and a little ammonia being about all required for most purposes. It would not be possible in the limits of a lecture to more than outline the work necessary to properly prepare specimens of iron and steel for a thorough microscopical examination. We will, therefore, briefly run over the more essential particulars, trusting that, with the list of tools above given, a fair idea of the work required may be obtained. The metal to be tested is first cut into pieces small enough to be conveniently handled upon the stage of the microscope; the standard size adopted by the Royal Experimental Station in Berlin is a short, cylindrical piece of metal about $\frac{3}{8}$ inch in length and $\frac{5}{8}$ inch in diameter. After the metal has been filed or turned down to a proper size, the surfaces to be etched are carefully filed off with a fine file, and then further ground down on a glass-plate with fine emery. After all the inequalities of the surface are removed, the metal should be carefully polished upon a hard whet-stone, thus removing all the coarser scratches made by the emery. After thoroughly washing and cleaning the specimen, it is ready for etching, which is an exceedingly difficult operation to properly perform. It is best effected with very dilute nitric acid, of about one part acid to

1,000 of water. Dr. Wedding uses platinum chloride, salicylic acid and a mixture of tincture of galls and acetic acid, for coloring the etched surfaces. It may be well to take this opportunity to call more particular attention to the above method of coloring and etching, which is as unique as it is beautiful. After the metal has been etched and treated with the above chemicals, it is carefully heated, whereupon the portions most readily attacked by the acid acquire varying tints, mostly golden-yellow, purple-red, violet, or dark blue. Dr. Wedding claims that the differences of these colors are characteristic of the different elements present in the metal; he fails, however, to prove this statement. The time necessary for the proper etching of specimens varies greatly, according to the quality and chemical composition of the metal. It would therefore be impossible to specify any definite space of time in which the different kinds of metal should be exposed to the solvent action of the acid. Perhaps the best plan to pursue is to remove the specimens, one at a time, from the acid about every half hour, and subject each to a careful examination with a lens or small microscope. After a little experience, one can generally tell when the etching has gone far enough, in which case the specimen is carefully washed, dried, moistened with kerosene, and placed in a tightly corked glass phial until wanted for examination. The easiest way to "mount" the etched specimens is simply to fasten them to ordinary glass microscopic slides with sealing-wax, care being taken that the etched surface be perfectly parallel with the plane of the glass slide, and consequently parallel with the object-glass of the microscope when under examination.

MICROSCOPES.

It would be difficult to say just what kind of microscope would be best adapted for this kind of work, as there is such a great variety of sizes and shapes in the market. As a general rule, however, the simplest in construction, are the best, particularly so for persons unfamiliar with the use of delicate instruments. For general work, and for the proper application of photography, it is important that the microscope shall fulfil the following requirements:

(1.) The stand should be of the best workmanship and material; there should be no "shake" or lateral motion; in the adjustment of the focus, there should be no "lost motion"—that is, the

focus should instantly change with the slightest motion of the milled heads—and for photography, there *must* be a universal joint, for inclination.

(2.) The instrument must be provided with a fine adjustment-screw, with a groove turned in its periphery.

(3.) The mirror under the stage should be so constructed that it can be made to swing over, around, and above the stage, thus affording a means of more intense illumination to the object than otherwise could be obtained with opaque substances. The objectives should be of the very best quality. Experience has shown that it is poor economy to use any others.

There have been several microscopes specially designed for this work, probably the best and most ingenious of which is that used by Martens, of Berlin.* "It consists of an ordinary microscopic tube, fitted with suitable lenses of moderate power, and the novelty consists chiefly in the way it is mounted. It is held above the table by a knee-piece, fitted at each end with a large ball and socket joint, which can, by means of set-screws, be fixed in any desired position, the more delicate adjustments being effected by the usual rack-and-pinion arrangement. The table itself contains a large circular opening, in which rests a half-sphere, the level surface of which seems as an object-table, and by simply turning this sphere, the object can easily be brought into any desired position, so as to get the best inclination for both light and observation. In order to prevent this spherical table from sliding too freely, its surface is wiped over with a little tallow. The makers of this modified instrument are Messrs. Schmidt & Haensch, of Berlin. A plain parallel glass is fitted in front of the object lens, so as to protect it from danger by coming in contact with the object under investigation."

USE OF PHOTOGRAPHY.

One of the great difficulties in all kinds of microscopic work is to illustrate it properly, that others may see on paper what the investigator sees under his instrument. Naturally, the simplest way to effect this would be by means of drawings, but as every microscopist knows, it is an exceedingly difficult, tedious, and by no means accurate way of illustrating. Investigators have, therefore, availed themselves of the recent rapid development of the

* *Iron Age*, November 2, 1882. Vol. xxx, No. 18.

science of photography, and consequently have simplified their work enormously. Of course, photographs are not so clear and distinct as drawings, but, on the other hand, they are obviously more accurate, and can be made at a small cost of time and money. A good negative once obtained, is of far greater value than a drawing, as it can be reproduced an indefinite number of times by means of prints. When a large number of illustrations are wanted, as in printing, electrotypes can readily be made from the negatives by the various photo-engraving processes.

The camera used for microscopical photographing is made especially for the purpose, and differs from the ordinary cameras in

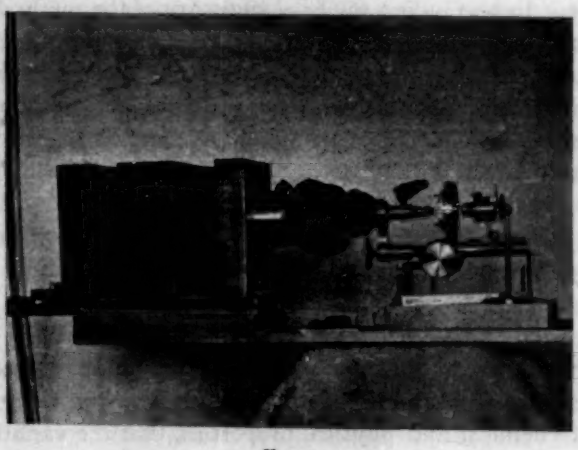

FIG. 1.

having a larger bellows—capable of being extended a couple of feet—and in place of the lens there is a paste-board cone about six inches long, into which the microscope tube is inserted. In *Fig. 1*, is shown the entire apparatus ready for use; the camera and microscope are fastened securely to a long, narrow board made for the purpose, thus giving stability as well as accuracy and convenience to the entire apparatus. The open joint where the camera and microscope are connected, is closely wrapped around with a piece of dark cloth, to prevent any extraneous light from entering. As will be noticed in *Fig. 1*, the camera is small, using a 4¼ x 5½ inch plate. This size is found by experience to be the most convenient,

and, for most purposes, meets all the requirements of this kind of work. Owing to the difficulty of sufficiently illuminating opaque objects, so as to obtain a good image upon the ground glass, it is very essential that the exposures be made in good, strong sunlight, and that the light be concentrated by some means upon the object. There are a number of instruments which can be used for this purpose, but perhaps the best and simplest is an ordinary bull's-eye condenser. Lamp light is sometimes used, and, when the objects are transparent or translucent, it answers very well, but for opaque objects it is not to be recommended. The sensitive plates should be only of the very best quality, should have great density, and, in short, be as near perfect as possible, besides being as sensitive as they can be made. In concluding my brief summary of the methods of preparation and treatment of the different kinds of iron and steel to be investigated, I should remind you that if success in this, as in all other kinds of scientific research work, is desired, the student must needs have plenty of patience, and use the greatest care in the pursuit of his work. He should not depend much upon the work of others, but take up and study each and every detail for himself. His work would then be of value as original, and unbiased by the opinions and theories of others.

WE WILL NOW TAKE UP the microscopic structure of the different varieties of iron and steel in detail, referring here and there to their different chemical and physical properties, that the variations and peculiarities of structure which they exhibit may be better understood.

As pig and cast iron are probably the most common and useful varieties, we will consider them first. Pig iron, as is well known, is divided into three classes, determined by the color of the metal, which is due almost entirely to the varying amounts of graphitic carbon present: gray iron, containing the most; then mottled; and, lastly, white, which contains hardly any at all. Carbon is usually present in all kinds of iron and steel in two conditions; namely, as combined or amorphous, and as graphite. There is very possibly a third condition, but as its existence is by no means proved, we will therefore not consider it. Upon the total amount of carbon, and upon the relative amounts of the two conditions in which it is

present, depends in great measure the quality of the metal, and the essential difference between iron and steel. It is very difficult to draw the line sharply between iron and steel, or between steel and wrought iron; but for ordinary purposes, if the metal contain from 1·5 to 4·5 per cent. *total* carbon, it may be considered as cast or pig iron; from 0·15 to 1·5 per cent., as steel; and from 0 to 0·15 per cent., as wrought iron.

Gray pig, or cast iron, to the naked eye, has a grayish-white to a black appearance; sometimes lustrous, by reason of the large size of the graphite flakes or patches. It is usually hard, brittle, and, when of good quality, quite tough If an excess of graphite is present, it is apt to be so soft as to be worthless; other things being equal, if it contains less than 3·5 per cent. of total carbon, it is pretty sure to be of good quality. Its specific gravity is about 7·1, and its other physical properties variable and dependent upon its chemical composition. In *Fig. 2*, is shown the structure of gray coke pig iron (No. 2), as seen under the microscope with a magnification of fifty diameters. The structure shown, is that characteristic of all good qualities of gray pig or cast iron, the shaded lines and patches being the graphitic carbon, which is always prominent in good iron and becomes less so as the metal deteriorates in quality. The surrounding metallic mass presents a compact, granular, non-crystalline structure, frequently containing cavities, due to occluded gases or air. Sometimes the graphite appears to group itself in clusters, or knots; especially if the quality of the metal is inferior, there seems to be a decided tendency for these graphite flakes or patches to form in this manner. Of course, small cavities caused by gas or air may easily be mistaken for graphite, in a hasty or superficial examination, but with a little care and careful focussing, the difference can readily be detected.

Fig. 3 exhibits the structure of mottled-iron, the mottled aspect to the naked eye is not apparent under the microscope. It will be noticed that the quantity of graphite in this metal is not so great as in the gray iron, and that it appears to be more leafy and more in patches. With a high magnification, however, the little worm-like graphite plates, which are undistinguishable in the illustration, can easily be detected. As we have seen, the larger sizes of these plates are quite characteristic of the gray iron, but such can hardly be said to be the case in mottled iron, as they are

too minute. In mottled iron, it would, therefore, seem that the graphite is not only less in quantity than in the gray, but also that it is in a much finer state of division, although, of course, there are intermediate grades in which these conditions do not exist. To what the mottled appearance to the naked eye is due, it would be difficult to determine; it may possibly be caused by the uneven distribution of the graphite. Some grades are nothing but mixtures of gray and white iron, hence the mottled appearance can easily be accounted for. In *Fig. 4*, we have shown the structure of white pig, or cast iron; its structure, both under the microscope and to the naked eye, being distinctly crystalline. The intensity of the crystallization depends very much upon the degree of chilling, there being substantially no difference between chilled and white iron. In a large casting made in a metallic mould, the outer surface, which comes in contact with the mould, will be found to exhibit a highly crystalline structure (as shown in *Fig. 4*), while the inner part, which has cooled more slowly, will show little or no crystalline structure. One peculiarity of chilled iron is, that the crystals are always arranged with their axes normal to the surfaces of the mould. When magnified to a comparatively high degree, the metal appears deeply furrowed, these furrows running parallel to the long axes of the crystals and appearing to separate them. I have never been able to detect any graphite plates in white iron, although there may possibly be a very few in some grades of the metal. The dark-shaded places, noticed in *Fig. 4*, are caused by the furrows between the crystals.

White or chilled iron is harder than the hardest kind of steel; it is brittle and difficult to work. Its principal use is for the treads of car-wheels, and recently, I have been informed, it has been used with great success for machine tools.

WROUGHT IRON.

Like cast iron, wrought iron may be classified under three heads; namely, forged, rolled and drawn. If we take a piece of wrought iron and fracture it by bending it back and forth, we will notice that it is built up of separate laminæ and fibres. If the metal has been rolled, or drawn, we find the fibres parallel and running in the direction in which the metal has been rolled.

In *Figs. 5* and *6*, we have a longitudinal and a cross section of

such—of rolled iron, as it appears under the microscope. In *Fig. 5*, the parallel fibres spoken of, are very distinct, the dark-shaded parts being cavities containing intermingled slag. It is impossible to obtain any wrought iron in which slag or other impurities cannot be detected by the microscope. In *Fig. 6*, a cross section of the same piece, the fibres are seen on end, as it were, the deeply-shaded parts being cross sections of the slag cavities, seen in *Fig. 5*. There is no trace of crystalline structure, ordinarily, in wrought iron, and I doubt very much if its structure can be crystallized by strains, vibrations, or shocks. I have seen many instances in which wrought iron was said to have been so changed; but on investigation, I was never able to prove that it had been, or that the crystalline structure seen on the fractured surfaces, had not been there before the rupture took place. It is true that iron bars will sometimes snap right off in a most unaccountable manner, and the fractured surfaces have a crystalline appearance, but after a most careful examination of such specimens with the microscope, I have been unable to detect the slightest trace of a *true* crystalline structure.

The fibres, or laminæ, of the metal seem to be suddenly snapped in twain, showing no trace of stretching or bending, and the fractured surface is smooth with a crystalline *appearance*. On close examination with the microscope, however, this crystalline appearance disappears, and the fractured surfaces show the fibrous structure "on end," as it appears in *Fig. 6*. The structure of drawn malleable iron is essentially the same as in the illustrations (*Figs. 5* and *6*), the fibres, or laminæ, being drawn out parallel to each other, instead of rolled. In forged iron, the conditions are altogether different, the fibres being knit or welded together. In *Fig. 7*, which shows the structure of a weld of iron and steel, this structure is fairly well defined; as the magnification, however, is necessarily low, the fibrous structure is not as well shown as could be desired. The granular portions of the metal, which can be readily distinguished, running through the centre of the cut, are due to the steel present, which has not been altered by the forging. If the illustration be examined with care, it will be noticed how closely the two metals are knit together. The cavities (shown by the shaded places) are due to imperfect forging and to the presence of cinder or oxide of iron (scale). The quality of the metal

obviously depends as much upon the perfection with which the fibres are knit together as upon anything else; hence it is important that these impurities should be eradicated as far as possible, for if not, they are apt to become worked between the fibres and prevent their being closely united. It is practically impossible to obtain any forging, however perfect, altogether free from these foreign substances, unless some means to prevent the formation of scale or oxide can be devised. Of course, this amount can be reduced to a minimum by thorough and careful forging.

STEEL.

The rapid growth of our steel industries, and the enormous extent with which steel is being employed in the arts, renders it imperative that our knowledge of the properties of this great metal should be more perfectly known. That as yet we know very little about them, every metallurgist and iron manufacturer will tell you, and the wonder is that we are able to make steel as good and as cheaply as we do. Chemistry and the testing machine have doubtless taught us much, and probably will teach us much more, but it seems eminently desirable that some new and other means be obtained, wherewith we can learn more of the physical properties, minute structure, and peculiarities of both iron and steel. That the microscope will, to a considerable extent, supply these wants I am well assured, and I trust that before I finish my lecture, you will agree with me. As you all know, there are two kinds of steel, hard and soft, each being made in an entirely different manner. The hard or tool steel, is usually made in small crucibles, while the soft or malleable steel is made in the Bessemer converter, the open-hearth, or by some other pneumatic process. The microscopic structure of hard or tool steel is very simple, as will be seen in *Fig. 8*. It is hard, compact and granular, very rarely containing any impurities, such as slag, cinders, or oxide of iron. This hard granular structure is usually regarded as crystalline, and, to the naked eye, it frequently does appear as such. As will be noticed in *Fig. 8*, it is truly granular without a trace of crystalline structure. The amount of carbon in tool steel varies according to the temper from about 1·15 to 1·50 per cent—this, of course is combined, as there is ordinarily but a trace of graphitic carbon present. Its specific gravity is about 7·90.

There is practically no apparent structural difference in the various grades of tool steel, except that the grains, or granular structure, is larger or smaller as the case may be. As a general rule, the finer the grain, the harder the metal, and the greater the amount of carbon it contains. Except a small quantity made by methods in use many years, the great bulk of the soft steel now used is made either by the Bessemer or the open-hearth process; it is with these latter, therefore, we have to deal. There should be theoretically no difference in the product of these two processes, but, as a matter of fact, there almost always is not only a little, but a considerable difference. The product of the open-hearth furnace is usually much superior in every way to that of the Bessemer, and as its operations require much more skill and care, its cost is proportionally greater. Its use is chiefly for purposes where high tensile strength and elasticity are required, as in boilers, fire-boxes, ship-plates, etc.

As the general microscopic structure of open-hearth steel is very similar to that of the Bessemer steel, we may leave its consideration for another opportunity, and continue with the latter. Bessemer steel is produced from cast iron, by the combustion and consequent removal of some of its carbon. This is effected in what is known as a "converter," which may be described as a huge crucible, through the bottom of which a strong blast of air is forced. After the molten metal has been blown from twenty to twenty-five minutes, and the proper stage of decarbonization reached, the blast is shut off, and a certain amount of highly-manganiferous cast iron run into the converter. This metal is known as ferro-manganese, or, when containing a smaller amount of manganese, as spiegeleisen. It is added to replace a certain amount of carbon removed from the blown metal, and to add manganese to the steel, which is supposed to greatly increase its strength and durability. The metal (steel) is then poured into a large ladle and cast into ingots, which are reheated and rolled into rails. The greatest difficulty encountered in this process, is to obtain a uniform product and homogeneity of the metallic mass; the former is ordinarily obtained, but the latter rarely indeed, and, as far as my experience goes with steel rails, it is never obtained. In *Figs. 9* and *10*, we have respectively a longitudinal- and cross-section of a bolt made of Bessemer steel, the structure shown here being

decidedly "steely," having the characteristic compact and granular appearance of steel. As in former cases, the shaded parts are due to cavities and furrows, but these are caused, however, not so much by intermingled slag and other impurities, as by gas and air cavities in the ingots. When the ingot is rolled, these cavities, of course, are elongated into furrows as in *Fig. 9*. Some idea of the vast number of such cavities and furrows can be formed by examining *Fig. 10*, which shows those of the previous figures "on end." Such imperfections cannot but be detrimental to the strength and durability of the metal. There is probably no department of metallurgy in which the microscope can be used to greater advantage than in the study of the minute structure of steel rails, and there is certainly none upon which we need more information. It was with this end in view that I took up the work a short time ago. The results obtained have so far been eminently satisfactory to myself, although as yet but a very small amount of work has been accomplished. Enough, however, has been done to convince me of the great lack of uniformity and homogeneity of Bessemer steel, as it is ordinarily produced.

In making microscopic examinations of a steel rail, a section about a half inch thick, should be cut from the middle of the rail. The section should then be divided into small pieces about an inch square, so as to show as far as possible the structure of the different parts of the rail. These pieces should be equally divided into longitudinal- and cross-sections, for by this means a very good idea of the structure of the entire rail can be obtained. The difference of structure in the head, web and flanges should be carefully noted. In *Fig. 11*, we have a cross-section from the head of a sixty-seven pound (sixty-seven pounds per yard in weight) steel rail, which had been in use nearly ten years. Its structure has the same granular characteristics always found in steel, but, unlike the best qualities of that metal, its structure is *irregular*, some portions being softer and much more easily attacked by the etching acid. These soft places are indicated in the illustration, by the dark shaded patches or blotches. They are probably caused either by an irregularity of chemical composition, or by some mechanical defect in manufacturing; though just what the defect is due to, it would be difficult to say, since it may be derived from a

variety of causes. * In the year 1880, Herr Martens, the well-known engineer and microscopist, noticed similar defects in the steel rail in use in Germany, and in the article referred to, which he wrote at that time, he attributes them to the rolling out of the blisters or gas cavities which were originally in the ingot. He contends that with even the most careful working, it is doubtful if they can be entirely eradicated, and that, although steel containing a large number of them, will sometimes have a high tensile strength, their presence cannot but be detrimental. The illustrations which he gives with his paper, show a structure almost exactly the same as ours. In *Fig. 12*, we have a longitudinal section taken from the head of a sixty-eight pound rail in use six years. Passing directly through the characteristic compact granular structure of the steel, we will notice a large streak of metal, which appears to have been affected to a much greater degree by the acid than the bulk of metal. In this case, as in the cross section, it is probably caused by the rolling out of blisters, gas cavities, or to soft places in the metal, due to an irregular chemical composition.

We have now hastily examined the structure of the more important varieties of iron and steel, we have noted their structure, and the characteristic differences between each. It therefore only remains for me to impress the fact upon you, that each of these varieties constitutes a separate field of research within itself; indeed, the metallurgy of iron and steel itself is so divided up, that one man is a specialist in pig iron, another in wrought, still another in steel, and so on; to thoroughly understand it, each must make a scientific study of his specialty. If the use of the microscope can aid him in this work, and thereby enable him to produce a better product, enriching himself and the world besides, I shall feel abundantly repaid for the hard work I have had in endeavoring to introduce this instrument into metallurgy as an instrument of research.

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* *Glasers' Annalen für Gewerbe und Bauwesen.* December 15, 1880. No. 84, p. 476.

THERMODYNAMICS.

By Professor De Volson Wood.

(*Continued from page 140.*)

This rate, then, involves the imperfection of the gas. We will attempt a more general explanation. The higher an imperfect fluid is heated at a constant volume, the more nearly will it approach to the condition of a perfect gas. Thus, in the equation before given

$$p\,v = R\,\tau - \frac{a}{v} - \frac{a}{v\,\tau} - etc.$$

the larger τ is, the more nearly does $p\,v = R\,\tau$; and, conversely, the less τ is the more imperfect is the fluid, and p increases less for a given increase of τ than if it were a perfect gas. Hence, between τ small and τ large, p must increase more rapidly for an imperfect than for a perfect fluid. This granted, it follows that the rate $\frac{d\,p}{d\,\tau}$, or $\frac{d\,p}{d\,Q}$, is greater for an imperfect than for a perfect fluid, other conditions being the same, as already shown by the equation above. This being the virtual increase of the pressure for one degree of temperature, and the rate being maintained constant at the temperature τ by the absorption of heat, and since all the heat absorbed must have Q units of heat and is transmuted into work at that heat, the virtual pressure during the expansion $d\,v$ will be Q times the above rate, or

$$Q\,\frac{d\,p}{d\,Q} = \tau\,\frac{d\,p}{d\,\tau},$$

hence, the total work, both external and internal, for the isothermal expansion $d\,v$ will be

$$d\,W = \tau\,\frac{d\,p}{d\,\tau}\,d\,v$$

and for an isothermal expansion from v_1 to v_2,

$$W = \int_{v_2}^{v_1} \tau\,\frac{d\,p}{d\,\tau}\,d\,v = \tau \int_{v_2}^{v_1} \frac{d\,p}{d\,\tau}\,d\,v. \qquad (11)$$

So much for the analysis and the symbolic representation of the

second law. As we have made no reference, thus far, to that law, the question may be asked: What is its use? Why not dispense with it? There is an advantage in stating the fundamental principles of a science in the form of laws. They are like the foundation-stones of an edifice, they show on what the structure rests. Subjects may be developed in accordance with fundamental principles without statements of formal laws. Newton's three laws of motion have served, and continue to serve, a good purpose in the development of mechanics. The science of thermodynamics is developed by some writers without a reference to a second law, or even the formal statement of any laws. The first law is an expression of the equivalence of heat and work. The second law is an expression for the total work deduced from the external during an isothermal expansion. Let the point be emphasized that the kinetic energy—the heat energy—of a pound of a fluid, or of any given mass of it, depends directly upon its absolute temperature, so that if the latter be maintained constant during a change of volume, the heat-energy will be constant. This can be proved directly for perfect gases, and is believed to be true for imperfect ones, at least in a constant state of aggregation.

We now examine the wording and the meaning of Rankine's second law, as quoted in the early part of this paper. This is the law that Maxwell pronounced "inscrutable." Rankine made several statements of this law, including symbolic expressions of it, but they do not all cover the same ground. Some intensify one point and some another, but they do not antagonize each other, and must be considered as containing a common principle, and if any one of the statements does not cover all the principles necessary for the establishment of the analysis, it must be considered defective or incomplete; otherwise there would be several different laws all claiming to be the second. Rankine expressly states that these several statements are intended to be essentially the same.

According to the symbolic expression already investigated above, the law must contain the idea of isothermal expansion. Certainly, the law contains no such statement explicitly, and if found there at all, it must be in the words "causing work to be performed;" and in order that these words shall convey this idea, it must be considered that neither the substance nor the heat in the substance does the work, but that it is merely an agent for

transmitting the heat from the source to the working-piston, or to some other potential form. But there is no intimation that there is a source of heat, and since this is a necessity, it must be inferred on account of the conditions of the problem; and the temperature of the source must be at least as high as that of the substance. The principle contained in this last statement is sometimes referred to as the second law, viz.: "that heat cannot of itself pass from a body of a lower temperature to one of a higher;" but most writers, especially Rankine and Thomson, consider this as an axiom, and make the second law include a measurable quantity. A source of heat, then, is a necessity, and must be understood in Rankine's second law; or, we might say, as before stated, that the fact of a constant temperature must be admitted, for otherwise the law does not furnish a foundation for the analysis. It will be admitted that the interpretation we have given of this part of the law is somewhat forced; that naturally the words will not convey the idea which we have imputed to them; and that it may be questionable whether they should be so understood; but if not, then the statement of the law is incomplete in this particular. Either the "scope" of the words must be very large, or more words are needed. Rankine, in one of his original papers, supplied the necessary words in a sentence which is so clearly and fully expressed that we copy it, italicizing a part of it:

"Let us conceive that unity of weight of any substance occupying the bulk V under the pressure P, and possessing the absolute quantity of thermometric heat, whose mechanical equivalent is Q, undergoes the indefinitely small increase of volume $d\,V$; and let us investigate how much heat becomes latent, or is converted into expansive power during this process, *the thermometric heat being maintained constant, so that the heat which disappears must be supplied from some external source.*"—(*Misc. Sc. Papers, p. 311.*)

If the "disappearance of heat" in the quotation near the beginning of this article is the same as "*the heat which disappears*" in this last quotation, as it ought to be, we see no good reason for retaining the words "of this" in the former quotation. To retain them, only compels a forced and awkward repetition.

The italicized words contain a principle which should be included in the second law, if it is to furnish a complete foundation for the symbolic expression. Next, consider the expression, "The

total actual heat." This is simply the heat which remains in the body as heat; it is not the heat absorbed by the body, for such heat may have been expended in doing external work, in which case it is no longer heat, none of it being retained as heat; or some of it may have been expended in effecting molecular changes of some kind, called internal work, in which case so much of the heat disappearing in this potential form is no longer heat, although its effect remains in the body. All the heat absorbed by the body remaining after deducting all that has been changed to potential energy is "actual heat" or "total actual heat," it is sensible or thermometric heat. The law states: "If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts," etc. The divisions here mentioned may be conceived as produced in two distinct ways, first, by dividing the substance into equal parts, which, in the case of a uniformly hot, homogeneous substance, will divide the heat into the same number of equal parts, and each part will have the same temperature, and secondly, by conceiving the heat in the entire substance to be produced by equal increments beginning with zero heat. There is nothing in the nature of the case, nor in the language of the author, up to this point, that compels the acceptance of one of these modes of division to the exclusion of the other, and hence the one which will furnish the clearest explanation of the solution sought, will naturally be accepted. For this reason, we conceive that the heat is divided by dividing the mass of the substance. For the sake of greater definiteness, conceive that the substance is in an ordinary steam cylinder, and that it is divided into an indefinite number of prisms having their basis against the piston at one end and the head at the other. The heat of the substance being Q, the amount in each small prism will be $d\,Q$, when the prisms are indefinitely small, and the number of such prisms will be

$$\frac{Q}{dQ};$$

and the amount of work which each can do by expanding an amount $d\,v$, the thermometric heat, Q, being maintained constant, will be

$$\frac{d\,p}{d\,Q}\,d\,Q\,d\,v,$$

and since all those parts are not only equal but altogether alike in nature and similarly circumstanced, their effects must be equal, therefore the entire energy must be the effect of one of the parts multiplied by the number of parts, or

$$\frac{Q}{d\ Q} \times \frac{d\ p}{dQ}\ d\ Q\, d\ v = Q\ \frac{d\ p}{dQ}\ d\ v,$$

which is the symbolic expression of the second law. It may be noticed that this process is slightly different from that in the text, for there the factor $d\ Q$ is integrated, while here it is cancelled in the operation of multiplying, but the results are the same. The fact is, we have here followed the precise process, amounting to nearly a literal quotation, of the author in his original paper, read January 5, 1853 (*Misc. Sc. Papers*, p. 204).

As to the other mode of division, that by increments of heat, it will lead to the same result by a deduction from the former by making the increments of heat, $d\ Q$, the same in value as the heat in one of the small prisms. It needs no argument to show that this is possible, and hence, numerically, the value of the last expression will not be changed by this mode of division. But as an independent proposition, it raises this vital question—does an element of heat, $d\ Q$, low down in the scale, say, for instance, at $\frac{1}{4}\ Q$, cause the same work as the last $d\ Q$ when the heat becomes Q, and if not, how can it be said that "the effect of each of those parts in causing work to be performed is equal?" This mode of division gives a scale of temperature, and so we repeat the question in this form: Is it plain that an increment of heat, $d\ \tau$, will cause the same work to be performed by a pound of gas when the temperature is $\frac{1}{4}\ \tau$, as when it is τ? It can easily be shown to be true for perfect gases in which increments of pressure vary directly as the increments of temperature, and in which also the total work is external, but can it be asserted as equally true for imperfect gases? Before we complete this discussion, these questions will be definitely answered and the obscurity, if any, in regard to the proper mode of dividing the heat into equal parts, will be removed.

As a consequence of the relation between the sensible heat and temperature, we have directly

$$\frac{d\ Q}{Q} = \frac{d\ \tau}{\tau},$$

thus reducing the former expression to

$$\tau \frac{d\,p}{d\,\tau} d\,v$$

The last expression has been established in a variety of ways. M. Clausius, Thomson and Joule first considered it in the form

$$\varphi(\tau) \frac{d\,p}{d\,\tau} d\,v,$$

in which $\varphi(\tau)$ was an unknown function, to be determined by experiment, and it was so determined by Joule and Thomson, as recorded in Thomson's *Mathematical and Physical Papers.* M. Mayer assumed it to be simply the absolute temperature itself; while Rankine, from his hypothesis of molecular vortices, deduced the form,

$$\varphi(\tau) = \tau - x,$$

x being the absolute temperature on the perfect gas-thermometer corresponding to the total privation of heat, whose value is very small—at first found to be about 2·1° C.—but after the experiments of Thomson and Joule, with the porous plug, it was found that the error resulting from considering $x = 0$ would be less than those resulting from the errors of observation, since which it has been considered as zero, and we have

$$\varphi(\tau) = \tau,$$

and to this expression Thomson has given the name "Carnot's function." Knowing this result, as Rankine did when he wrote his *Manual*, he assumed it, and so greatly abbreviated the investigation. In regard to expression $Q = k\tau$, Rankine remarks, at the close of his celebrated paper "On the Geometrical Representation of the Expansive Action of Heat," (*Trans. Roy. Soc.*, 1854; *Misc. Sc. Papers*, p. 409,) that it is a hypothetical principle, "and that, although existing experimental data may not be adequate to verify this principle precisely, they are still sufficient to prove that it is near enough to the truth for all purposes connected with thermodynamic engines, and to afford a strong probability that it is an exact law." This conclusion has been verified in many ways within the ranges of temperatures used in ordinary practice.

Rankine gives two other statements of the second law in the *Manual*, one expressed in regard to absolute temperature graphi-

cally expressed, the symbolic expression of which, $\tau \frac{d\,p}{d\,\tau} d\,v$, is the one most frequently used; the other, a functional relation, which results in the same value as that just given. In his other writings, are several other statements; for instance, in the *Engineer*, of June 28, 1867, is the following:

"If the substance which does the work in a perfect heat-engine receives all the heat expended at one fixed temperature, and gives out all the heat which remains unconverted into work at a lower fixed temperature, the fraction of the whole heat expended, which is converted into external work, is expressed by dividing the difference between those temperatures by the higher of them, reckoned from the absolute zero. Now this is, in fact, the second law of thermodynamics expressed in other words." (See also *Misc. Sc. Papers*, p. 436.)

Yes! exclaims the student, "in other words" this statement is explicit and easily understood, but one does not recognize it as the equivalent of that in the *Manual*. *This* is a mere ratio, *that* the measure of a quantity; *this* is the fraction of the whole heat converted into external work, *that* a measure of both external and internal. The statement includes isothermal expansion, and, taken as a whole, may be made the basis of an analysis for producing the expression $\tau \frac{d\,p}{d\,\tau} d\,v$. This is the principle used by Clausius, Thomson, and other writers, for deducing the symbolic expression; and it is probable, if not certain, that Rankine had this operation in mind when he wrote the various expressions for the second law.

Again, in the same article referred to above, is another expression, as follows: "That law (the second) is capable of being expressed in a variety of forms, expressed in different words, although virtually equivalent to each other. The most convenient form for the present purpose appears to be the following:

To find the whole work, internal and external, multiply the absolute temperature at which the change of dimensions takes place, by the rate per degree at which the external work is varied by a small variation of the temperature."

This is explicit, but with the exception of the first eight words, it is merely substituting words for the algebraic expression

$$\tau \frac{d^2 U}{d\tau} = \tau \frac{dp\,dv}{d\tau} = \tau \frac{dp}{d\tau} dv.$$

Isothermal expansion is asserted in the words, "the absolute temperature *at* which the change of dimensions takes place." The change takes place *at* a constant temperature. Here, the author explicitly states that the work done during isothermal expansion includes the internal work, and the same fact may be inferred from other parts of his writings. According to the last quotation, it follows that any statement of principles, which is sufficient for the establishment of the expression $\tau \frac{dp}{d\tau} dv$ may be considered as the second law. Laws forming the foundation of a science should be simple, explicit, avoiding ambiguity, and complete in their assertions. The one we are considering does not conform to these conditions, and is at best only a remote suggestion of a physical operation. We propose to amplify it, so as to make it include all the principles necessary for the establishment of the symbolic expression, using substantially the language of the author as found in different parts of his writings, as follows:

SECOND LAW.—*If work is done by the expansion of a homogeneous and uniformly hot substance, the thermometric heat being maintained constant by a supply from an external source, and the total actual heat be conceived to be divided into any number of indefinitely small parts, each of the parts being not only equal, but altogether alike and similarly circumstanced, their effects in causing work to be performed will be equal; the total work performed being the external and internal during the expansion.*

I would substitute for all these, and other expressions, a principle common to all of them, and common also to the corresponding principles in the writings of Thomson and Clausius, as follows:

SECOND LAW.—*The work, both external and internal, done during the expansion of a substance at constant temperature, equals the heat absorbed.*

When thus stated, the analyst is free to choose his own method of determining the heat absorbed during isothermal expansion, and when found, the law states that it equals the work done during the absorption. One way of determining the heat absorbed is as follows:

Let a substance capable of indefinite expansion, whose initial volume is $o\,v_1 = v_1$, *Fig. 2*, and pressure $v_1\ A = p$, expand at constant temperature τ, from $o\,v_1$ to $o\,v_2 = v_2$; then will the locus $A\,B$ of the upper ends of the ordinates representing pressures, be an isothermal line. Through A pass the adiabatic $M\,A$, and through B the adiabatic $B\,N$, then if the adiabatics be indefinitely extended, they will be asymptotes to $o\,x$, and the indefinitely extended area $M\,A\,B\,N$ will be the heat absorbed during the expansion from v_1 to v_2. To find this area, conceive it to be intersected by isothermals differing from each other by $d\,\tau$, then will the number of strips be $\frac{\tau}{d\,\tau}$. The area of these strips will equal each other. To prove this, we use Thomson's absolute scale of temperatures. Conceive that the substance after expanding to B expands without transmission of heat until the temperature falls $d\,\tau$, the pressure will fall until

it reaches the consecutive isothermal $f\,e$; then compress the substance along $f\,e$ isothermally, during which operation heat will be rejected by the substance, the amount of rejection being represented by the area $M\,e\,f\,N$, then compress the substance without transmission of heat adiabatically along $e\,A$ to A. The resultant work will be represented by the area $A\,B\,f\,e$, and this also represents the heat which disappears by this operation.

Now, if when B is reached, the expansion be prolonged adiabatically until the temperature falls $2\,d\,\tau$, the pressure will fall until it reaches the second isothermal, then compress along the second isothermal until $M\,A$ is reached, then compress adiabatically to A. Since no heat is lost along the adiabatics, but all that is lost is along the isothermals, twice the heat will have been abstracted in the second as in the first operation, and the area of the

two strips will be twice that of the upper one. Proceeding in this manner we show that all the strips are equal, so that the area of any one multiplied by the entire number, will give the entire area $MABN$. In the case of perfect gases, it is easy to find the area of any one of the strips, for the equation to the adiabatics are known, but generally, it is easiest to find the area of the topmost strip, where p and v are known. At any point a in Ab draw the vertical ad to the next isothermal, and construct the vanishing parallelogram $adcb$; its area will be $dp\,dv$, and the area

$$ABfe = \int_{v_1}^{v_2} dp\,dv.$$

But this cannot be integrated since dp is variable, decreasing from A to B. But, for any assigned value of v, p is a function of τ only, and since $d\tau$ is constant from A to B, we express dp as a function of τ. This, according to the calculus, may be expressed thus:

$$\frac{dp}{d\tau}d\tau$$

and our expression becomes

$$ABfe = d\tau \int_{v_1}^{v_2} \frac{dp}{d\tau} dv$$

where $d\tau$ is placed outside the integral, since it is constant. If $\frac{dp}{d\tau}$ contains τ, the integration may be performed, because τ is also constant from A to B, or from v_1 to v_2. To illustrate, the differential of the most general form of the equation for imperfect gases, already given in equation (6), is

$$\frac{dp}{d\tau} = \frac{R}{v} + \frac{a}{v^2\tau^2} + \frac{2a_2}{v^2\tau^3} + \text{etc.},$$

which contains τ, but since that and $d\tau$ are to be constant from A to B, the integral may be performed, giving

$$Abfe = d\tau\left[R\log\frac{v_2}{v_1} + \left(\frac{2a_1}{\tau^2} + \frac{4a_2}{\tau^3} + etc.\right)\left(\frac{1}{v_1} - \frac{1}{v_2}\right)\right].$$

Observing that the area of each strip equals that of $Abfe$, and that the number of strips is $\frac{\tau}{d\tau}$, we find the area

$$MABN = \frac{\tau}{d\tau} d\tau \int_{v_1}^{v_2} \frac{dp}{d\tau} d v = \tau \int_{v_1}^{v_2} \frac{dp}{d\tau} d v,$$

which is an expression for the total heat absorbed during the isothermal expansion, and hence equals the total work done.

It remains to be determined whether Thomson's absolute scale can be measured by a thermometer constructed of actual materials.

This scale would be represented by a perfect gas-thermometer, for all the work done by a perfect gas expanding isothermally will be external. Thomson and Joule made a series of delicate experiments upon air, known as the experiments with a "porous plug," to determine if air could be considered as a perfect gas when used as a thermometer, and it was found that the errors resulting therefrom were not greater than the errors resulting from direct observation, so that τ may be considered as the absolute temperature measured with an air-thermometer, and a good mercurial-thermometer agrees sufficiently well with the air-thermometer to be used in ordinary practice.

In the light of this solution, it may be asked: Is it not the heat absorbed during expansion that is to be divided into equal parts? While it is certain that it is so divided, it is equally certain that it is not the heat to which Rankine referred, when he said: "Let unity of weight of the substance possessing the actual heat Q . . . Conceive Q to be divided, etc." It is not the source of heat, nor the heat absorbed that is, fundamentally, divided into equal parts; but the heat of the working substance. We are explicit on this point, because we find that such an eminent author as Prof. Cotterell appears to have fallen into an error on these points. We quote from page 111, of his work on *The Steam Engine*, as follows:

"Let us now imagine the temperature T_1 of the hot body, or source of heat, to be divided into n equal parts, and let us imagine a quantity of heat, Q, to flow from that body to a second body, the temperature of which is $T_1\left(1 - \frac{1}{n}\right)$, then our results show that a quantity, $\frac{Q}{n}$, of mechanical work is capable of being produced, and that, consequently, if such conversion be effected, the quantity $\frac{n-1}{n} Q$ will pass into the second body. Now, imagine

a third body, the temperature of which is $T_1\left(1-\frac{2}{n}\right)$, and let this heat pass from the second body to the third body; then the heat capable of being turned into work, is

$$\frac{n-1}{n}Q \cdot \frac{T_1}{n} \cdot \frac{1}{T_1\left(1-\frac{1}{n}\right)} = \frac{Q}{n}$$

as before. This process may be continued indefinitely, and we thus see that—*If the temperature of a source of heat be divided into any number of equal parts, then the effect of each of these parts, in causing work to be performed, is the same.*"

Here the temperature—not the actual heat—is imagined to be divided; also, the source of heat is divided, not the heat of the working substance; also, Q is the quantity of heat imagined to flow from the source, while in Rankine's analysis, Q is the actual heat of the working substance. It is not clear what the division of the source into equal parts has to do with this analysis. This quantity, Q, is independent of the amount in the source, and also of that in the working substance; and it is assumed that this amount flows from the source *to* the second body, but that only an amount $\frac{n-1}{n}Q$ flows *into* the second body. The conclusion is also unfortunate, at least in form, for it reads as if the equal temperatures caused work to be performed, instead of equal heats. This attempt to explain Rankine's second law is, to say the least, not a success. The assertion that equal quantities of heat will do equal quantities of work, is nothing more than the first law.

In the case of a perfect gas, Rankine's operation of the second law, may be thus: Let one pound of the substance possessing the actual heat Q be conceived to be divided into n equal parts. While the substance possesses the actual heat Q, let it expand against a resistance doing work while its heat is maintained at Q by a supply from an external source, and after it has expanded by enlarging the vessel an amount $v_2 - v_1$, *Fig. 2*, let it be brought back in any manner to its original state of volume v_1 and heat Q; its pressure will then also be the initial, or p_1. Now, let $\frac{1}{n}$th of Q be abstracted from the substance at the constant volume v_1, the

pressure will fall to $(1-n)\,p_1$, after which let the substance be again expanded at the constant heat $\left(1-\frac{1}{n}\right)Q$. the same amount, $v_2 - v_1$, as before. Repeat the operation, by expanding it, the same amount, as before, from v_1 to v_2, at the heat $\left(1-\frac{2}{n}\right)Q$, and so on. Then will the difference between the works done during the successive expansions be equal. It is in this sense that "the effects of the equal parts in causing work to be performed are equal." The operation may be represented geometrically by dividing the space $v_1\,A\,B\,v_2$ into n strips by isothermal lines extending from $v_1\,A$ to $v_2\,B$. This divides the external work $v_1\,A\,B\,v_2$ into equal parts, and since, in a perfect gas all the work will be external, the division accomplishes the purpose sought. The actual heat absorbed, $M\,A\,B\,N$, will also be divided into the same number of equal parts by the same isothermals.

But when the fluid is imperfect, this process will not divide the external work into equal parts, and much less afford any measure of the internal work, for the internal work is a function of the volume as well as of the temperature, as shown by the equation preceding (6). To illustrate the case for imperfect fluids, conceive successive isothermals drawn as before starting on the ordinate $v_1\,A$, but extended to the right to the adiabatic $B\,N$, then will the successive strips between the adiabatics be equal. For the area $M\,A\,B\,N$ represents heat—not work—and it will be divided into successive equal increments of heat. As the heat falls in temperature, the strips become longer and narrower, their areas remaining constant. It is this complex operation that is involved in the expression, "the effects of the equal parts in causing work to be performed are equal." The operation is known as Carnot's cycle, and we are thus brought to Thomson's Prop. II, and Clausius's mode of analysis. This solution admits of but one mode of division of the actual heat Q; that of a division according to a thermometric scale from zero to Q, and is unquestionably the mode of division intended by the author. It is not a division of the substance in which each part would have the original temperature of the substance, but one in which the temperature of the entire substance is reduced by the abstraction of equal quantities of heat from the substance. The equal parts of heat do no work, but are

indices of the grade of the heat doing the work. All of the heat doing the work must be of the grade Q, but to find the work which the heat absorbed can do, we conceive it to be worked in a perfect reversible engine, first at the grade Q, next at the grade $Q - dQ$, third at the grade $Q - 2dQ$, and so on, as already described, in which neither the beginnings nor endings of the works are arbitrary, but are limited by one pair of adiabatics. The phrase, "causing work to be performed," is not even suggestive of the manner according to which the work is to be done. Carnot's cycle is fundamental. Although Rankine deduced it from an independent hypothesis, yet had his analysis conflicted with this principle, the hypothesis and not the principle would have suffered.

We have thus established definitely the essential, and, we believe, the correct, meaning contained in the paragraph quoted at the beginning of this article.

(*To be continued.*)

ALUMINIUM AND ITS ALLOYS; WITH EXPERIMENTAL INVESTIGATIONS.

By Edward D. Self, Stevens Institute of Technology.*

Should we assume the existence of a metal superior in valuable properties to iron, and predict its entrance into the arts as a far more useful servant to man, even the remote possibility of such an event would be an interesting subject for discussion.

When, however, we can with truth point to the presence of such a metal in immeasurable quantities, it is indeed remarkable that in this age of progress such a wonderful substance should be so generally regarded simply as a chemical curiosity—the result of an interesting experiment.

This universally distributed metal, though now disguised, excels iron in lightness, is nearly equal to it in strength, does not rust or corrode by acid vapors and, what is more striking, is the third in respect to abundance of the constituents of the earth's crust.

This metal for which the arts have long waited, is aluminium, or "silver made from clay."

* Graduation Theses, 1886.

Mountains and valleys everywhere contain aluminium as their chief treasure, and even our city pavements are really ore-beds of a metal far more valuable than iron.

Though aluminium has been isolated and its wonderful properties known for over half a century, its production has hardly emerged from the form of a large laboratory experiment, and it is now so costly that it is far from occupying its true place in the arts.

At the present time, however, strenuous efforts are being made to cheapen its manufacture; and it may be that we can see and almost stand upon the threshold of an age of aluminium.

Yet so great have been the difficulties attending its cheap production in the past, it is perhaps best to be not too sanguine of new processes or results, until they have had more than a theoretical or experimental demonstration.

The history of this metal, though it forms but a brief chapter, has not, so far as the writer is aware, been written, except in the very briefest way, and chiefly exists, at present, in diffused and disconnected statements of discoveries and claims for new methods of manufacture.

As all the processes in vogue depend on the use of expensive chemicals, any slight change in manipulating the steps of the process, or use of the by-products, may materially reduce the final cost. It is doubtless for this reason that the details of manufacture have been so scrupulously guarded.

HISTORY.

Lavoisier first suggested the existence of metallic bases of the earths and alkalies at the beginning of the present century, but he was unable to isolate them.

Twenty years later, Sir Humphry Davy succeeded in obtaining metallic sodium and potassium, but he labored in vain to isolate the base of alumina. The next twenty years were marked by the labors of Berzelius and Oersted, the latter of whom was able to replace the oxygen in the Al_2O_3 by chlorine, and then tried to obtain metallic aluminium by making an amalgam with potassium. The metal he thus obtained somewhat resembled tin in appearance, and he thought he had at last discovered the long-sought base. Wöhler subsequently wishing to prepare this amalgam from very pure substances, found it impossible to do so, and could not arrive at Oersted's result.

While thus the work of Oersted was unsuccessful, it marked an epoch in the history of aluminium from the direction it gave to all future experiments. He was the first to use the chloride which is now regarded as almost indispensable, and upon the use of which, in some form, depend all the commercial processes of manufacture at the present time.

This use of the chloride suggested to Wöhler the practicability of directly employing the chloride and some reducing agent. As a result of his labors in this direction, he was able, in 1827, to isolate the metal in the form of a gray powder, which, from its comminuted state, possessed few of the characteristics of the solid metal, and was exceedingly variable in its properties. It was also frequently contaminated with potassium sodium and their chlorides.

He also obtained very small quantities of the metal by heating the chloride and potassium in a closed platinum-tube. The aluminium thus produced was very infusible, as it doubtless contained platinum. We read with interest, as a sequel to these preliminary labors, that he discovered minute metallic globules in the gray powder of aluminium in 1845, but it was more than ten years later before he could produce these globules even of the size of a pin's head.

The labors of Wöhler had, in the meanwhile, interested many men of science, and among these the name of H. Sainte-Claire Deville stands pre-eminent. By him, the properties of the metal were first clearly demonstrated.

While endeavoring to produce a chloride of aluminium by heating certain substances in a furnace or muffle, he discovered, at the end of the operation, some shining metallic globules adhering to its sides. Elated by this discovery, he at once devoted all his energies to produce the precious metal in larger amounts. He began his work by using a glass tube, about four mm. in diameter, in which were introduced 250 grammes of $Al_2 Cl_6$, free from iron; this was separated in one portion of the tube, which was then heated with the rest, while hydrogen was passed over the chloride.

The hydrogen and the volatilized chloride then passed together over metallic sodium previously inserted, and the chloride was reduced to the metal. Finding that the obstacle to commercial success was the price of sodium, costing 2,000 francs per kilogram, in 1855, he exerted himself towards cheapening its production,

and brought its price down to at least within the possibility of using it for his purposes.

Deville, at this time, was a professor in the École Normale, Paris, where much of his work was carried on. The French Academy soon became interested in the subject of aluminium, and appointed Deville one of a committee to prosecute more thoroughly the experimental investigations he had already begun. Napoleon III also aided him with a present of about $7,000, and he began his great work for which he is famous.

Dumas says: "In saying that Mr. Wöhler discovered the metal, it should be added that Deville made it of greater purity and first showed its qualities for industrial purposes."

In 1855, we see for the first time a bar of aluminium in the Palais de l'Industrie, and the following year, Dumas showed to the Academy the first kilogram produced. These were important events in the history of the metal, as, up to 1854, it was produced only in the form of a powder by Wöhler's method. The next year, a helmet was made of the metal for the King of Denmark, and shown by Dumas to the Academy. It was then stated that the manufacture of sodium had been so greatly cheapened that aluminium could be easily produced in large quantities at 100 francs per kilogram. But while Dumas greatly underestimated its cost, its price fell from 3,000 francs per kilogram, in 1857, to 300 francs in 1859.

In 1867, it again appears in the Palais de l'Industrie, and, eight years later, in various marketable forms, as castings, sheets, foil, wire and finished goods, polished, engraved and soldered.

Deville, soon after his methods were deemed successful, started a factory in connection with Debray and P. Morin, at the works of Rousseau frères. Their processes were subsequently improved under the direction of Morin, at Nanterre; and also improved methods were used by Merle & Usiglio, at Salindere, near Alais. Twelve years after the metal had appeared in the form of castings and finished goods, the Paris Exhibition of 1879, showed that its production had reached a maximum, at which it has since practically remained.

The French were the first to carry out Wöhler's method, or, rather Deville's modification, on a practical scale, and it is the only country in which the industry has really prospered. Extensive

experiments were, however, early made in Berlin by Prof. H. Rose, and by Gerhard, in England, tending to cheapen the metal. Later, I. Lothian Bell attempted to manufacture aluminium commercially at Newcastle-on-Tyne, but about 1874 he was obliged to close his works.

Wirtz & Co., in Germany, also tried in vain to make its production a success, but it has still been left to the French to make it successfully, into the forms demanded by commerce, at Salindere and Nanterre.

Within recent years, vigorous efforts have been made in this country and again in England, to compete with the French manufacturers. In this country, the Cowles Electric Smelting and Aluminium Company are at present erecting a large plant at Lockport, N. Y., to produce aluminium and its alloys from corundum by a process of electric smelting.

In England, the manufacture is carried on by the Webster Aluminium Crown Metal Company, which makes, besides the pure metal, a number of valuable alloys. This company recently (in 1883) made a very elaborate display of their finished products in London, before sending their exhibit to the Calcutta Exposition.

ORES OF ALUMINA.

Aluminium is the most widely distributed metal on earth. It is never found in the metallic state, but always combined with oxygen and in this form, Al_2O_3, is the basis of many of the commonest rocks and the chief constituent of most clays. It is found in porphyries, igneous rocks, and in connection with quartz in granite, gneiss, mica, schist, syenite and some sand-stones, while sapphire and ruby consist exclusively of it.

A very brief glance at the pages of any manual of geology shows that a very large per cent. of aluminium-bearing rocks contain over sixty per cent. of aluminium, while a large number contain over eighty and nearly ninety per cent. of the oxide. These minerals are widely distributed both in this country and Europe, but from reasons partly of a commercial nature, the deposits of French clay or bauxite, at Beaux, near Arles, France, the English and Irish clays and the cryolite from Evigtok (Greenland), and from

Norway, are the most familiar as aluminium-producing ores. By the methods of electric smelting, such refractory ores as emery and corundum can be used advantageously.

The utility of cryolite and bauxite was early discovered, and upon the use of one or both of these minerals, most of the early and many later methods depend. Wöhler employed cryolite and showed many of its properties, among which, perhaps, the most important is its lightness, enabling it to be used as a flux, which will float on the surface of the molten metal. This circumstance is of great importance, as will be seen, when we remember that the density of aluminium is only about two and one-half times that of water.

At the time of Wöhler's experiments, cryolite was imported to Germany as a "mineral soda," and was used for washing purposes.

While bauxite and cryolite have been held in about equal favor in the past, a recent experimenter informs the writer that bauxite possesses many advantages over cryolite.

Alumina appears in the kaolin deposits in Connecticut, New York, Virginia and Georgia, etc., etc., and is a large constituent of many common clays. The black clays, shales and slates, occurring with and between coal seams, frequently contain twenty to over thirty per cent. of Al_2O_3. Minerals containing seventy to eighty per cent Al_2O_3, are sometimes found with corundum or emery at Chester, Mass., Newlin and Unionville, Pa., Franklin, N. J., and Amity, N. Y.; while there is said to be a veritable mountain of sulphate of alumina in New Mexico.

VARIOUS METHODS OF PRODUCTION.

The following methods, or perhaps theories, for the production of aluminium are given with one that has proved itself to be of commercial value. The others are presented not wholly as being important in themselves, but as a guide to future experimenters.

In 1854, Deville employed a modification of Wöhler's method, by heating to a red heat a mixture composed of sodium and chloride of aluminium in a porcelain crucible. The excess of the chloride collecting together in a mass, in the centre of which was found globules of more or less pure metal.

He subsequently passed the vapor of Al_2Cl_6 over metallic sodium inclosed in a tube of iron or copper, and kept at a red

heat. As might now be supposed, the metal thus produced was very impure. Afterwards making it on a larger scale, he passed the vapor of the double chloride of Al and Na over metallic sodium, at the same time employing cryolite or fluorspar as a flux, the vapor being produced by heating the following ingredients together:

Chloride of Al and Na,	10 parts.
Fluorspar, or cryolite,	5 "
Sodium,	2 "

The double salt and the fluorspar, or cryolite, were pulverized and mixed together in proper proportions with the sodium also in small pieces. The whole mixture was then placed in a reverberatory-furnace that had first been raised to a red heat—the air being always excluded. A very violent chemical action at once takes place and great heat is evolved. When the reduction has proceeded sufficiently, the slag and then the metal is run out. By this method, with a furnace containing about sixteen square feet, about sixteen pounds of pure metal was produced.

Aluminium was prepared by Heinrich Rose, of Berlin, directly from cryolite, by mixing this mineral with half its weight of common salt, and arranging this mixture in a crucible with sodium in alternate layers, and in the proportion of sodium two parts and cryolite mixture five parts. A great advantage was claimed for this use of cryolite, because it obviated the use of the single or double chloride of aluminium, and was itself a natural product found in large quantities. One of the chief difficulties was that, as the crucibles were either of iron or clay, the metal was considerably contaminated with iron or silicon and from which it was impossible to free it.

But, however successful the work of Rose might have been, Deville, Rousseau and Morin concluded that it was best to prepare the chloride of aluminium and then decompose it by sodium.

The first industrial preparation of the pure metal was effected by distilling Al_2Cl_6 in a vertical retort, and passing the vapor through a cylinder containing fifty to sixty kilograms *de pointes de fer*, and heated to a low red heat. From this, the vaporized chloride passed into another cylinder containing 500 grams of metallic sodium placed in small dishes.

The Al_2Cl_6 produced in the first dish a double salt of Al and Na, which vaporized and passed with the excess of the chloride to

the next dish, where more of the double salt was similarly produced. The whole then passed on to the third dish of sodium, where it was reduced to the metal and chloride of sodium.

When this action was completed, fresh dishes of sodium were substituted. This process was afterwards modified by using at first the double instead of the single chloride.

When the utility of cryolite as a flux had been demonstrated, Deville, Debray and Morin employed the following proportions:

Double Chloride,	400 grams.
Salt,	200 "
Fluoride of Calcium,	200 "
Sodium,	75 "

in which the fluoride was replaced by cryolite. The double chloride and fluoride, or cryolite, were pulverized and mixed together and arranged in alternate layers with sodium in iron or earthen crucibles, which were first moderately heated and then the heat increased until the mass melted.

If the operation was successful, about twenty parts of the metal was obtained in a compact mass, while about five more were encrusted in the slag. The same difficulty occurred in this process as in the one already mentioned; the metal became alloyed with iron or silicon.

Several ingenious methods have been devised to avoid the use of the chloride, and in its place use alumina and its sulphate. The one to be described can be operated either in a crucible, or, on a larger scale, in the following furnace. This furnace properly consists of three shaft-furnaces, made of some refractory material, two of which can be closed by an iron cover or other contrivance. They communicate with each other by channels, which can be closed by slides. Two of the furnaces contain some fuel (as coke), and in these are provided steam and air-blast pipes; the latter making it possible to obtain a very high temperature. When in use, the middle furnace receives its charges in the following order: After the other two have been blown very hot, first a mixture composed of $Na_2CO_3 + C + S + Al_2O_3$ is inserted; then sulphate of alumina is added, and finally a flux, usually composed of the chlorides of sodium and potassium. The middle furnace is first made hot by burning some coke in it. The charge is placed immediately upon the coke, and as the latter burns away, the former

gradually sinks to the bottom. After this, it is generally necessary to mix coke with the charges. One of the heating-furnaces is now shut down, and steam is blown into and decomposed over the glowing coke; the oxygen liberated forming carbonic-oxide, and the hydrogen remaining uncombined. The gases thus produced pass, while highly heated to the central furnace containing the charge. The first result is to decompose it into sodium-sulphide and aluminium-sulphide, which are reduced together by the second charge (sulphate of alumina). The metallic sodium does not appear, as it at once performs the same office as in the chloride methods of reduction described.

The reduced aluminium can now be drawn off as it passes into the melting-zone of the furnace. When the reducing gases have become cooled, the other heating-furnace is operated in a similar way.

Instead of decomposing the charge into the bi-metallic sulphide of aluminium and sodium, pure aluminium-sulphide, or a mixture from which it can be produced, may be used; or pure sulphide of sodium, potassium or copper, or other metallic sulphide, producing the same effect on the sulphate of alumina. In the latter cases, however, the metal produced is alloyed with the metal of the sulphide.

The charge $Al_2O_3 + Na_2CO_3 + S +$ coal, may be changed to a mixture of Al_2O_3, S, and coal, only; and the process can be further simplified by employing one charge composed of sodium-sulphide and potassium-sulphide; the others being produced from Al_2O_3, or sulphate of Al_2O_3.

Different processes have been devised to cheapen the chloride methods of production, but it will be observed that they differ from the methods invented by Deville only in the merest technicalities of operation and description. One of these is to bring the fluoride or chloride of aluminium, volatilized in any way, into contact with nascent sodium, made by strongly heating the following mixture of—

62 parts, ...	Na_2CO_3
28 "	Coal.
10 "	Chalk.

or, in place of this mixture, any other may be used that will produce either sodium or potassium.

A method has been patented in this country by William Frishmuth, for extracting the metal from cryolite, corundum or bauxite, by first converting the materials into fluorides and then bringing them in immediate contact with sodium-vapor.

Equal parts by weight of the mineral and of fluorspar are dried together in a furnace, or crucible, at a bright red heat, to expel moisture. These materials are then pulverized, and to the mixture is added three-tenths ($\frac{3}{10}$) of its weight of fluoride of calcine. The mass is again heated and converted to a fluoride of aluminium and sodium. The double fluoride is then powdered and mixed with twenty per cent. of charcoal or some carbonaceous material, as oil. To each 100 pounds of this mixture is added twenty-five pounds of chloride of potassium, and ten pounds of chloride of sodium, the chlorides being first melted together. The whole mixture is now rolled into small balls, and thoroughly dried, after which they are placed in a retort with a perforated bottom. Through this bottom is conducted sodium vapor, made as follows, in another retort: Twenty parts by weight of calcined soda, ash or Na_2CO_3, ten parts of powdered charcoal, and five parts of chalk, lime or its carbonates. When these retorts are both highly heated, the sodium vapor produced, as above described, passes to the first retort, and reduces the metal from the fluorides.

This process can be changed somewhat, and instead of the fluoride of aluminium being first produced, the chloride is obtained. The required amount of the mineral is mixed with ten per cent. of fluoride of sodium or potassium, and sometimes an equal amount of fluorspar is added. After calcining, ten per cent. of carbonaceous matter, as oil or starch, is mixed with the mass, which is then rolled into balls and again dried. These balls are then placed in a furnace, through which a current of chlorine is passed, producing the aluminium chloride, which condenses in a separate vessel. In producing the fluoride from bauxite, it is likely to be contaminated with iron, and therefore it is preferable to decompose it with chlorine gas, the volatile chloride, which is made, being free from this impurity, and also others. The chloride may now be reduced in another retort, or it may be passed over metallic iron to free it from any iron chloride it may contain, and allowed to condense in another receiver. Metallic aluminium can now be obtained by passing the sodium vapor directly into this receiver.

These processes, in their general and principal features, are substantially the experimental methods at times used by Deville. In their present complicated form, they do not indicate a great commercial success.

Various interesting, ingenious, but at present unprofitable, methods for the reduction of alumina have been suggested, and depend partly on the use of hydrogen, and the formation of various aluminium alloys.

One of these was patented by W. P. Thompson, for the manufacture of Al, Na, etc. The operation was to be performed with an apparatus similar to the Bessemer converter, with either iron alone, or with hydrogen or carbon as the reducing agent.

After the iron was melted in one converter it was poured into the second, into which were forced streams of hydrogen or carburetted hydrogen, and chloride or fluoride of aluminium; the excess of hydrogen and ferric chloride being permitted to escape. At the end of this operation, an alloy containing a large amount of iron remains in the converter. This alloy is now transferred to the first chamber or converter, and the carbon is burnt out by a current of air. After being returned to the second converter, the reduction is continued until the iron is nearly burnt out, at which time hydrogen alone is to be used as the reducing agent. The iron, however, cannot be completely removed, and the final result is an alloy. When pure metal is to be made, sodium is used as a reducing agent, and into the chamber containing it the fluoride or chloride is allowed to enter.

The following hydrogen method was devised in England some years ago: Powdered fluoride of aluminium, either alone or with other fluorides, was heated in an air-tight furnace to a red heat, and at the same time was exposed to the action of hydrogen. Shallow trays of the fluoride were placed on the hearth of the furnace, preferably reverberatory, and surrounded by clean iron filings, in suitable dishes, to absorb the hydrofluoric acid produced on the admission of the hydrogen. The reduced metal was found at the close of the process at the bottom of the tray used for the fluoride.

The following attempt was made to obtain the metal by making an alloy of zinc. A series of steel retorts, 36 x 12 x 12 inches, having sides ⅞ inch thick, were used with the charge composed of—

Zinc ore,	100 parts.
Kaolin,	50 "
Carbon, anthracite coal, or its equivalent,	15 "
Chloride of Na,	10 "

The whole charge must be well mixed. The furnaces, which, it is said, must have a temperature of about 2,500° F., could be worked alternately, each receiving two charges in twenty-four to thirty hours.

ELECTRICAL METHODS OF REDUCTION.

Since the discovery of aluminium, efforts have been made at various intervals to reduce $Al_2 O_3$ by means of a current of electricity, and, as has been intimated, the work of the early experimenters has been in vain almost to the present time—as far as any practical results have come from their labors.

Deville and Bunsen used the battery in their investigations, and produced a very small amount of the metal electrolytically. The bath used was composed of two parts of chloride of aluminium and one part of salt. These ingredients were first pulverized together and then melted; the heat which was then evolved by their combination being sufficient to keep the solution very fluid. On passing a current from two Bunsen elements through the liquid, the metal was deposited on the platinum-pole in a fine powder. This was doubtless the furnace which Deville, while laboring under the patronage of Napoleon III, proposed to also use for purifying platinum, as the heat could be increased by increasing the current, until the impurities in the platinum were volatilized. After this first use of the electric-furnace, little progress has been made in the development of this mode of smelting until within very recent years. About six years ago, Sir William Siemens described a furnace designed to melt considerable amounts of such metals as platinum and iridium, whose fusion has always presented the greatest difficulties. His furnace, however, differed from Deville's, in that the electrodes were a carbon-rod and the metal to be fused, contained in a crucible made of graphite and surrounded outside by fine charcoal. An arc could thus be formed inside, and could be adjusted by suitable means.

The next year, Faure patented a furnace for the reduction of sodium and potassium; but although the plan appeared feasible, he did not put it in practical operation.

At the present time, there is a large factory in the course of

completion at Lockport, N. Y., and also in Germany, at Hamelingen, near Bremen, designed to produce aluminium, magnesium and kindred metals, by processes of electric smelting.

We have now followed very briefly the history of this mode of reduction; and as it is at present chiefly used in producing alloys of aluminium, we will leave its more detailed consideration to the chapter on aluminium-bronze.

FRENCH METHOD OF PRODUCING ALUMINIUM.

The process at present employed in various forms in France is, or rather has been, until within very recent years, the only one that has supplied the wants of commerce sufficiently to be regarded as an industry.

The following description of the methods in vogue at Salindere, is derived from a French authority of note.

The process differs from the one first used industrially, in that the double chloride of aluminium and sodium is substituted for the single chloride, Al_2Cl_6, though it is very hygroscopic, and, on becoming moistened, oxidizes to Al_2O_3.

The material chiefly employed at Salindere is bauxite, and the process consists briefly of the following steps:

(1.) Preparation of the aluminate of soda and the solution of this salt to separate the oxide of iron contained in the ore.

(2.) Preparation of Al_2O_3 by precipitating it from the soda solution with CO_2.

(3.) Preparation of the mixture of Al_2O_3, carbon and salt, and drying and treating with chlorine gas to obtain the double chloride.

(4.) Treatment of the double chloride with sodium to obtain metallic aluminium.

The aluminate of soda $Al_2O_3 \cdot 3(Na_2O)$ is produced by calcining a mixture of bauxite (Al_2O_3 and sesqui-oxide of iron), and carbonate of soda, and then dissolving and filtering off the soluble aluminate from the sesqui-oxide of iron. The alumina is now precipitated from the soda solution by CO_2, thus:

$$Al_2O_3 \cdot 3(Na_2O) + 3CO_2 + 3H_2O = Al_2O_3 \cdot 3H_2O + 3(Na_2CO_3).$$

The formation of the double chloride by the action of chlorine on a mixture of alumina, carbon and salt, is thus expressed:

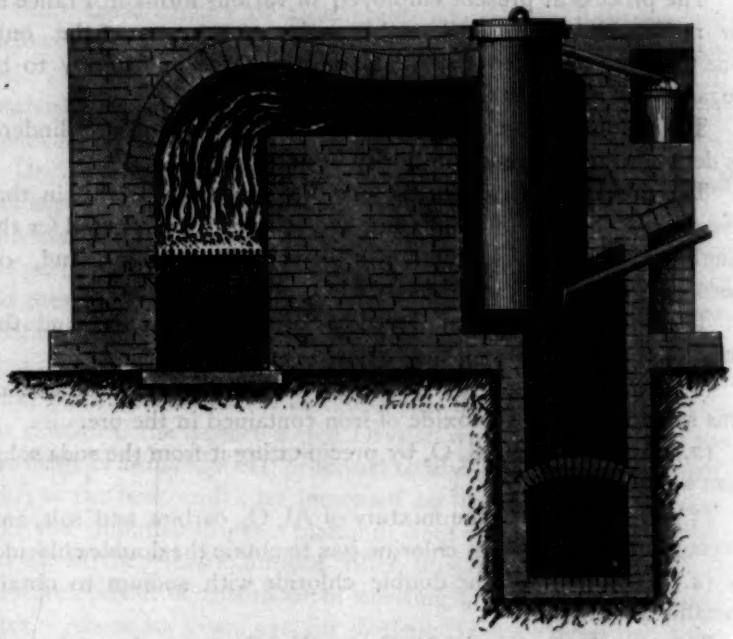
$$Al_2O_3 + 3C + 2NaCl + 6Cl = Al_2Cl_6 \cdot 2NaCl + 3CO.$$

Finally, the reduction of the double chloride by sodium is:

$$Al_2Cl_6 \cdot 2\,NaCl + 6\,Na = 2\,Al + 8\,NaCl.$$

The two illustrations show the general feature of the furnaces used; and it is thought with sufficient clearness to need no particular description.

The first shows the furnace for the production of the double chloride. This operation takes place after the ingredients are



placed in the vertical cylinder and the gas led in from below. The chloride condenses in the vessel on the right.

The second illustration represents the furnace for the reduction of the double chloride; here cryolite is used as a flux to protect the surface of the molten metal.

Considerable difficulty was at first experienced in aluminium manufacture to find a flux whose density was low enough and, at the same time, was free from iron.

Cryolite, however, seems to answer this purpose very well, and produces a very fusible slag beneath which the metal collects.

The proportions for the constituents of charge for the furnace shown is:

Double Chloride,	100 kilograms.
Cryolite,	45 "
Sodium,	35 "

The double chloride and cryolite are pulverized and mixed, and then divided into four equal parts. The sodium is divided into three parts, and is so put in that it has a layer of the double chloride and cryolite beneath it on the hearth of the furnace, and between it in successive layers, the top one being composed of the cryolite mixture.

As heat is applied, the first flow is melted slag, then aluminium, and finally a gray cinder, containing small portions of the metal.

PROPERTIES OF ALUMINIUM.

Aluminium is a silvery white metal, in many characteristics standing between zinc and tin. Its atomic weight is given by good authorities at 27·4 and 27·5, and density 2·5 to 2·67, when hammered. Its electrical conductivity was stated by Deville to be four times that of iron.

The following specific resistances of a wire, one metre long and one millimetre in diameter, are given in ohms as a result of Dr. Matthiessen's experiments:

Aluminium,	·03751
Iron, annealed,	·12510

Gold, annealed,	·02650
Silver, "	·01937

It is slightly magnetic and a very good conductor of heat. Its melting-point is somewhat higher than that of zinc, and it is said not to vaporize in the blast-furnace; though when boiling very rapidly, fine particles may be mechanically carried off from above its surface; on this fact is based one of the modes of separation already mentioned.

Its specific heat is variously stated at

·2143 Regnault,
·2020 Kopp,
·2183 Margottet.

When melted, oxygen readily unites with it producing Al_2O_3, so that, in casting, it is necessary to keep the metal covered with charcoal or strongly-burnt cryolite, to absorb the oxide that may be formed, and at the same time protect the surface. It fills the moulds well, and when proper care is taken, makes good castings in moulds of iron or sand. If, however, it does absorb oxygen or becomes alloyed with traces of silicon, it becomes gray and brittle. For this reason, the crucibles used should be lined with carbon or calcined cryolite. The remarkable properties of the metal, in resisting corrosive agencies, are almost destroyed if it is contaminated during its manufacture or subsequent manipulation.

Aluminium can be easily polished and finished like silver in a solution of caustic potash. It is not attacked by sulphuretted hydrogen, ammoniac sulphide, or nitric acid, except at boiling temperature; nor is it acted upon by vegetable acids. Solutions of sulphates and nitrates do not injure it, and may be used for electro-plating solutions.

Hydrochloric acid is its true solvent.

The chief difficulty that has precluded its use has, of course, been its cost, and, next to this, a general ighorance of its properties and manner of working. It is, nevertheless, used for many optical and mathematical instruments, jewelry and fancy articles, where combined strength and lightness are desirable.

Many interesting speculations have been made as to the effect aluminium would have on commerce if it could take the place of iron—being nearly equal to soft iron in strength, and with a density of 2·6, while iron is about 7·2. It is easily seen that the

changes that would be produced in engineering, by the introduction of such a metal, would be unparalleled in the history of the world.

It has been proposed many times, in Europe, to use this remarkable metal for coinage, as it possesses two properties in the highest degree suited to this purpose—it is exceedingly light and is not easily tarnished. But the difficulty that will doubtless forever bar it from this use, is the difficulty of re-melting without loss from oxidation; for, it must be remembered, that when it has been again converted to alumina, it is of little more value than the ore from which it was brought, by a long and expensive operation.

The tensile strength of aluminium can be greatly increased by hammering it when cold, and its ductility admits of its being readily worked, under the hammer, into exceedingly thin sheets. The tenacity of cast-aluminium bars of one-ninth to one-sixth square inch section is given in the *Berg und Hüttenmänn Zeitung*, as 13,590 pounds, and the same cold-hammered as 25,120 pounds per square inch.

Seaton, in *Marine Engineering*, gives a tensile strength of eight tons per square inch, and states that after being treated, as above, the tenacity can be increased from seven tons (cast-metal) to about twelve tons per square inch.

METHODS OF SOLDERING ALUMINIUM.

The great difficulty of uniting two pieces of this metal by solder or flux, has been a very great drawback to its use even where the price was not a fatal objection. The trouble seems to be that when strongly heated for brazing a thin film of alumina is produced on the surface that effectually prevents a union of the solder and metal. This has also been found to occur with alloys of aluminium. However, by employing special care, pieces of the metal can be united by the following processes, some of which from the cost of the ingredients are impracticable on a large scale.

One of the early solders employed was composed of aluminium two parts, and silver one part. This ran with difficulty and formed a somewhat brittle union. The following mixtures, composed of tin and bismuth, have been used quite recently and it is said with success:

Tin, ...	85 to 95 per cent., by weight.
Bismuth, ...	15 " 5 " "

For a soft solder, the mixture becomes

Tin,	99 parts.
Bismuth,	1 part.

to which is added one part of Al when a harder solder is required. The proportions above given can be changed to—

90 parts of tin, and
10 " bismuth

for soft solder, and to

90 parts of tin.
5 " bismuth.
5 " aluminium

for a hard solder. The constituents are in any case to be melted together and cast into bars. The pieces to be united are first thoroughly cleaned and moderately heated, and the solder is then applied with an ordinary "copper," using vaseline or paraffine as a flux.

In 1859, when the difficulty of joining two pieces of the metal was becoming evident to experimenters, Mourey suggested the following, which was claimed to be perfect in its results. Five mixtures are given in order, the softest being placed first:

	Zinc.	*Aluminium.*
I,	80 parts.	20 parts.
II,	85 "	15 "
III,	88 "	12 "
IV,	92 "	8 "
V,	94 "	6 "

The proper proportion of the latter metal is first melted in a graphite crucible; the zinc is then put in slowly, while stirring constantly. Small pieces of fat or grease are placed on the molten solder to prevent the oxidation of the zinc, which would produce brittleness. After the surfaces to be united have been carefully prepared by first melting on them some solder, that, on the above table, is soft in reference to the one to be finally used, and afterwards carefully cleaning and smoothing, the articles are secured together and strongly heated over an alcohol flame. The hard solder is then applied with an "iron" of aluminium. To facilitate the flow and adhesion of the solder, a mixture of three parts copaiba balsam and one part of venetian turpentine, with a few drops of a vegetable acid, is used as a flux into which the solder is merely dipped. Care must be taken when heating not to oxidize the zinc.

There is quite an expensive method for uniting one of the alloys by solder, which we will notice hereafter.

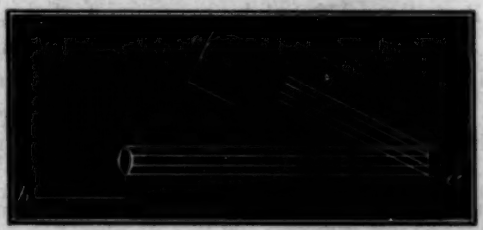
(*To be Continued.*)

HEAT-PHOTOGRAPHY.*

By F. E. Ives.

[*Read at the Stated Meeting, held Wednesday, February 16, 1887.*]

At the November meeting of this Institute, I described certain experiments in photographing by the aid of the phosphorescent-tablet, and announced the discovery of a means of photographing obscure objects by the action of heat-radiations. Since then, I have made several camera-photographs of metallic objects by the action of obscure heat-rays, which I placed the objects in a position to reflect. With a source of heat, produced with the consumption of coal-gas, at the rate of only three feet per hour, I obtained strong heat-photographs of small metallic objects, with camera-exposures of only ten seconds. But, although a moderate amount of heat was sufficient to give such striking results, it proved to be necessary, under ordinary conditions, to employ heat of a certain quality or intensity, which can be obtained only when the source of heat is also a source of light. My source of heat was the incandescent lime of the oxy-hydrogen light, placed in a dark box, one side of which was of black glass; the black glass transmits about thirty per cent. of the intense heat-rays, but no rays capable of producing phosphorescence, or of affecting bromide of silver. The arrangement is shown in this diagram:



a is the metallic object; *b* the camera; *c* the dark box containing the source of heat.

The object was focussed by the light-rays, allowance being

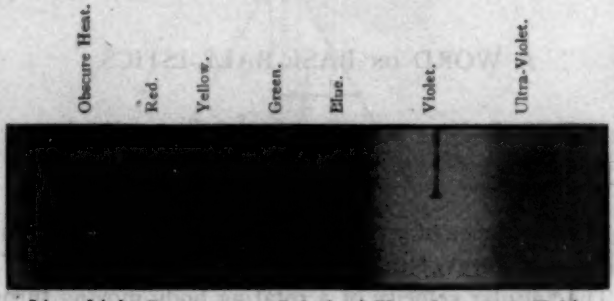
* This term may be objected to, but has been employed because the result of the method described is a fixed photograph of a fugitive thermographic impression.

made for difference of refrangibility of the heat-rays; the light was then extinguished by the black glass, and a solarized phosphorescent-tablet exposed in the camera. As I explained in my preliminary communication, this exposure produces a dark impression instead of the luminous impression that would be produced by violet light, and the photograph of this impression, made by contact-printing on a photographic sensitive-plate, is, therefore, a positive, instead of a negative.

I attempted to substitute a hot iron for the incandescent lime, as a source of heat, and even to photograph the hot iron itself, but without success. This might seem to indicate that the tablet is not sufficiently sensitive to the feebler heat-rays radiated by objects not heated to incandescence; but a simple experiment demonstrates that such is not the case. Contact with the hand for a single second will produce the characteristic sudden exaltation and partial exhaustion of phosphorescence in a tablet that has been kept at a sufficiently low temperature after solarization, and a simple calculation will show that enough heat is radiated from the hot iron to produce, in a little while, a strong impression in a camera some feet away. The knowledge of this and of the fact that rock-salt lenses transmit, and metallic mirrors reflect, these feebler heat-rays, led me to hope that I might photograph obscure objects without having to secure the special conditions that now appear to be necessary. My failure with the hot iron proved to be due to absorption of the heat-rays by aqueous vapor in the air. Prof. Tyndal found by experiment that the aqueous vapor in the air of his laboratory absorbed seventy times as much heat as the air itself. My experiments were conducted in very damp weather, and nearly all of the heat radiated by the hot iron was evidently exhausted in warming the air, and was carried away in air-currents. Although I did not accomplish what I hoped to in this direction, these experiments have made it evident that in a perfectly dry atmosphere, it would be possible to obtain photographs of obscure objects by the action of heat-rays of low intensity.

I have two illustrations of the method; one is a heat-photograph of a german-silver key-check, the other, a photograph of the impression produced on the solarized phosphorescent-tablet by the lime-light spectrum. The key-check photograph is quite small, but reasonably distinct. I believe it is the first heat-photograph

of an object that has ever been exhibited. The shadows of three pins are reproduced in the spectrum photograph; one was in the violet of the spectrum, another in the yellow, and the third at the lower limit of the visible spectrum. This photograph proves what I have already asserted,—that in Balmain's paint, phosphorescence is produced chiefly by the violet-rays, and the dark heat-rays below the visible spectrum act most powerfully to exhaust that phosphorescence. Exposures on the solar spectrum gave substantially the same result, but showed relatively more action by luminous heat, and distinct but very feeble action in a portion of the ultra-violet spectrum—the latter action was utterly insignificant as compared with the action of the same rays on bromide of silver.



Lime-Light Spectrum on Solarized Phosphorescent Tablet.

In my preliminary communication, I stated my belief that certain results that one M. Chas. Zenger recently claimed to have obtained by the aid of Balmain's phosphorescent paint could not have been obtained in the manner that he described. My later experiments confirm this belief, and I would not again refer to Zenger's communication had it not been widely published, attracting much attention. Balmain's paint is but feebly sensitive to invisible chemical-rays, glass lenses are practically opaque to all heat-rays radiated by bodies not heated above 200° F., and even a moist atmosphere will not transmit the feebler heat-rays to any considerable distance. If Zenger obtained a photograph of a midnight landscape in exactly the manner he described, it must have been by the action of light-rays that would have produced a much stronger and better photograph by acting directly upon the photographic sensitive-plate itself.

One other statement of M. Zenger's calls for correction by me.

He asserts that collodion-bromide emulsion-plates stained with chlorophyl are sensitive to all parts of the solar spectrum "from ultra-violet to ultra-red." More than seven years ago I discovered and published the fact that such plates are so remarkably sensitive to all colors as to be capable, with the aid of a weak yellow light filter, of producing correct-color-tone photographs of all colored objects; but it is not true that the sensitiveness extends to the ultra-red rays: it stops abruptly at the Fraunhofer line *a* in the red, as shown by spectrum photographs that have been made on such plates.

A WORD ON BASE-BALL-ISTICS.

By O. E. Michaelis, Captain of Ordnance, U.S.A.

AXIOMS.

(1.) The resistance of a medium to penetration increases with the velocity (rapidity) of penetration.

(2.) The angular velocity of a rotating body moving through a resisting medium is practically constant.

APPLICATION.

In *Fig. 1*, the ball is thrown in the direction *A B*, rotating to the left, as shown by the arrows. Evidently the hemisphere *A C B* rotates *with* the forward movement of the ball, and the hemisphere *B D A against* it. Therefore, the particles in the former are moving forward faster than those of the latter. Hence, by Ax. 1, the air opposes more resistance to the hemisphere *A C B* than it does to the hemisphere *A D B;* the ball accordingly follows the line of least resistance, and moves *inward*, as shown in *Fig. 2*.

When the "twisted" ball is delivered, its *initial* far exceeds its *angular* velocity. The first is rapidly reduced by the resistance of the air, the latter is not (Ax. 2); hence there must come a time when the angular equals, or possibly, exceeds, the initial velocity, then the ball will begin to "curve" rapidly.

CONCLUSIONS.

(I.) The trajectory of the rotating ball is always a line of double curvature—but the effect of the angular velocity at the beginning may be so slight as not to be perceived by the striker, who thus receives the impression that the delivery is "straight."

(II.) With a given twist (or angular velocity), a very "swift" ball would not "curve" enough; a very "slow" one, too much.

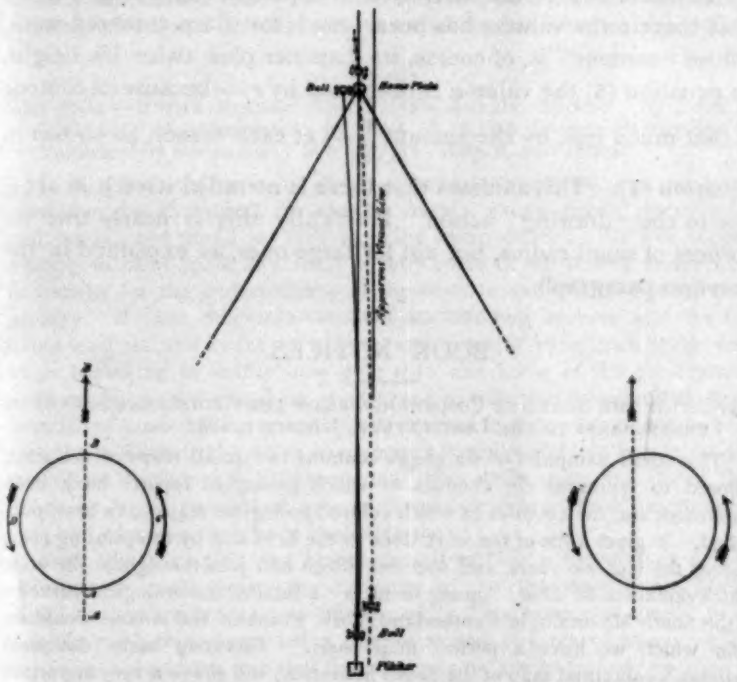


FIG. 1.
Centre of Inertia coincident with Centre of Figure.

FIG. 2.

FIG. 3.
Centre of Inertia not coincident with Centre of Figure.

The "scientific" pitcher is he, who, knowing this from practical experience, selects the most appropriate "pace."

(III.) A ball always deviates *with* the twist, unless it rotates about the axis of projection, in which case the twist will produce no deviation.

The above is a *popular* explanation.

The FLOW of METALS in the DRAWING PROCESS.

Addendum.

In Mr. Oberlin Smith's Lecture upon the "Flow of Metals," etc., upon page 23 of the Journal for November, 1886, equation (5) should read $2(r' + r'') - 2e = r$ — instead of with the sign of equality after the first 2, as the printer made it to read.

To make clearer the derivation of equation (3), it may be said that therein the value x has been found for sharp cornered work, whose "contour" is, of course, its diameter plus twice its height. In equation (6) the value x is decreased by r — because its contour is that much less, by the amount $\frac{r}{2}$ — at each corner, as shown in equation (4). This assumes that there is no radial stretch in arc e, due to the "drawing" action. Practically this is nearly true for corners of small radius, but not for large ones, as explained in the previous paragraph.

BOOK NOTICES.

Report of the Board of Commissioners of the Geological Survey of Pennsylvania to the Legislature, January 1, 1887.

This small pamphlet of six pages contains two small maps of the state, colored to represent the counties of which geological reports have been published, and the counties of which colored geological maps have been published. It gives a list of the work done in the field and by the printing-press during the last two years, and specifies fifteen odd jobs throughout the state which remain to be done, Among them, is "a detailed mineralogical survey" of the South Mountain, in Cumberland, York, Franklin and Adams Counties, "for which we have a perfect map basis." This map basis (doubtless Lehman's contoured map of the South Mountain) will prove a very important addition to the survey's records, but it was not known before this announcement that it was completed.

A "mineralogical survey" is one of those singularly unhappy expressions which, like human society in travail, 'voices a want for which itself cannot find words;' or, at least, the right ones. However interesting a mineralogical survey, or a search for minerals might be, a work more in keeping with the objects of the establishment and more important, would be the systematic study of the geological relations to each other of the several different formations represented in the mountain. It was for this purpose that the contoured map of the South Mountain was recommended and commenced under the direction of the former Assistant of the Southeast District of Pennsylvania. Why not allow his well-matured plan to reach fruition?

No proper effort has been made by the chief geologist to harmonize the conflicting views of the archæan and palæozoic geology of Chester, Delaware and Philadelphia, although they are parts of the geological column which are claiming the attention of geologists all over the world. It is a matter of speculation to what extent the "special local surveys in Chester and Delaware Counties" can conduce to this end. An appropriation of $90,000 is asked for the next two years. A great state like Pennsylvania should have a permanent geological bureau, economically administered, and charged with collecting, arranging and publishing the valuable information, which is lost in its absence every year. The head of such a bureau should be a man of large experience and industry, without prejudices that influence his work.

F.

THE STORY OF THE ROCKS. The Earth's Annular System. By Isaac N. Vail, with an introduction by Capt. R. Kelso Carter, Barnsville, O., Published by the author. 8vo, 375 pp. Appen. and Index.

It is a trait characteristic of most iconoclastic reform, that no matter what may be its subject, its apostles have a strong family resemblance, and argue (they would say reason) in the family dialect. We will suppose a being to have spent, say, thirty or forty years in the honest endeavor to fit himself for the understanding of the intricate and unsolved problems of geology. He has diligently searched out the best authors, and the best living teachers, and by the aid of both, and years of experience in the field, he is beginning to realize how little man can know of the great genetic problems connected with these studies, and to value the contributions to our knowledge made by the master minds devoted to them, though but a small part of the whole truth; when along comes a genius and tells him in the first line of his Preface that "the readers of this volume must first divest their minds as far as possible of pre-conceived opinions, however permanently time and education may have implanted them."

With this beginning, one braces oneself to hear a tremendous deliverance, which shall prove the necessity of "a thorough reorganization of the geologic record, as now interpreted." This turns out simply to be that the earth once possessed a ring, or system of rings, of aqueous vapor around its hot nucleus, and that the vapor was prevented from descending by the velocity of its rotation and by the heat of the central mass.

Most geologists, on reading this, will ask what it has to do with the "geologic record?"; and wherein consists its novelty? It has been held to be one of the probable transition states in the earth's genesis, ever since LaPlace (somewhat before Prof. Winchell) enunciated his "sublime conception," of which it is a corollary. As to the waters remaining suspended in the air for a considerable time after the earth was cool enough to hold them, very few could be found to take any other view: least of all that, that the waters descended all at once.

Amongst others, Dr. T. Sterry Hunt has very elaborately and graphically described this very condition of acid rains on the cooling earth, and perpetual clouds in the atmosphere, in his, "Some Points in Chemical Geology" (1857),

and "Chemistry of the Primeval Earth" (1867), (*Chemical and Geological Essays*, pp. 11 and 35), but it never occurred to him that he was revolutionizing the science. The idea that the fall of the water from the clouds caused the plications and upheavals of mountains, cannot be regarded as other than a forced and unlikely guess. It is scarcely worth while to say more of this book of Mr. Vail's, than that its main postulate is not new; its subsidiary deductions are not likely; and that the whole subject is of moderate importance compared to those parts of the history of the planet which relate to the gradual evolution of life.

It possesses a fictitious value by another effort to harness the poetry of the Hebrew Bible to the matter-of-fact deductions of modern science, and get out of the former more than its authors put into it. This attempt is also not new. It has baffled wiser men than Hugh Miller and Prof. Dana (the last chapter of whose *Manual* invites dreamers to continue in this unprofitable employment), and it is likely to continue to do so until it is abandoned like the ingenious word-puzzles of the schoolmen.

The idea that man's longevity was "impelled" by the suspension of aqueous vapor in antediluvian times (p. 95), so that he lived to 800 and 900 years, while his longevity diminished immediately after the "upper deep fell and the sun began to pour his beams upon the race," is somewhat startling; and, if true, must prove an entire change in the race since that time; for vital statistics show an increase in deaths (and especially in suicides) in cloudy weather. There could have been no rheumatism in antediluvian days.

Examples of the author's inaccurate logic are to be found widely distributed, such as the pressure of the atmosphere "unaffected by repelling heat," equalling so-and-so; "the equatorial belts of Saturn and Jupiter moving more rapidly than the polar, they must be moving independently of each other," etc.

Captain R. Kelso Carter also adds his quota to the non-sequiturs by stating as his sixth claim that "the falling of these rings to the earth somewhat weakened the cord of attraction for the moon, which therefore receded from the earth."

There are the usual defiances to science which attract only by their audacity in lieu of demonstration; the phrases and parts of phrases in italics, and the frequent recurrence of "it is evident;" "it stands proved;" "no one can deny;" "no sane man can for a moment doubt;" "we must draw the conclusion;" "tell me what else could have," etc.; "can we come to any other reasonable conclusion;" "the reader must see;" "there cannot be a man of reason who cannot see," etc.; "the annular theory declares to all the races of men under Heaven," etc.; "it must be admitted by every intelligent reader;" "it can readily be seen," etc. This is not the manner of a man who wishes to present a logical deduction of importance to his fellows. It was not thus that Aristotle, and Keppler, and Newton, and Bishop Butler and Darwin came before their fellow-men.

In short, the book is both pretentious and worse than useless. We hope for everybody's sake that the edition is small. F.

SCIENTIFIC NOTES AND COMMENTS.

PHYSICS AND ASTRONOMY.

NEW VIEWS CONCERNING SOLAR SPOTS AND FACULÆ.—Spörer (*Vierteljahrschr. der Astron. Ges.*, **20,** Heft 4) calls in question the long-received theory of Wilson, according to which the spots have been considered funnel-shaped cavities, extending considerably below the solar surface. Wilson (1769) saw the complete disappearance of the penumbra on the side of a spot next the centre of the sun, when the spot was about to disappear at the western limb, or reappear at the eastern, and this asserted fore-shortening of the inner side of the penumbra he attributed to the great depth of the spot. Spörer insists that the facts gathered from many years of observation are not in accord with this theory. For, on the assumption of considerable depth, the outer penumbra should, as the spot is nearing the limb, be last visible. But actual observation shows first the disappearance of the inner penumbra, then also the outer penumbra, while there still remains the umbra, and north and south of it, penumbra. This phenomenon, as well as the disappearance of small spots of groups nearing the limb, is due to the fact that around spots lie areas of faculæ, over which rise hot currents of gas, and through which the spots near the edge must be viewed. Moreover, computations of parallax due to depression, are not reliable, since the effect of the refraction of the solar atmosphere and of the parallax results in displacement in the same direction. Regarding the average displacement in a ten-year series, as due alone to the solar atmosphere, the refractive index comes out 1·0021; regarding it as due to depression below the solar surface, the average depth is only 2″. Many series of observations show no depression whatever.

The solar faculæ are produced by hot currents from the interior of the sun, while the spots are currents directed from the cooler atmosphere toward the centre, and are seen projected on the surface of the sun. The downward-directed currents diverge below and contribute to the force of the outward-directed currents of hot gases.

Rev. F. Howlett (M. N. Royal Astron. Soc., **46,** 447), contributes very careful measurements of individual spots with symmetrical penumbræ, which are in entire accord with the view of Spörer. In one instance, he insists that the following, or inner side of the penumbra, was wider than the outer, when the spot was but 20″ from the western limb.

M. Faye (*Comptes Rendus*, T. **103,** No. 14), while in general accord with Spörer's theory of solar currents, draws attention to the lack of a sufficient cause for the downward-directed currents in Spörer's hypothesis, and believes that this cause resides in the inequality of velocity of horizontal currents, producing on the surface of the sun, as in our bodies of water, or in our atmosphere, descending gyratory movements. Under the impulse of such a force cold hydrogen, in the form of a cylindro-conic column, is made to penetrate the denser layers of the photosphere. M. B. S.

NEW VALUE OF "v."—F. Himstedt (*Wied. Ann.* **29,** 560) has lately made a careful determination of the important physical constant "v," the ratio of the electro-magnetic and electro-static units of electricity. In the older determinations, differences amounting to as much as four per cent. appear, while the newest determinations of Exner, $29{,}20 \cdot 10^9$, Klemencic, $30{,}18 \cdot 10^9$ and J. J. Thomson $29{,}63 \cdot 10^9$ are not very much more in accord. Not only do Himstedt's five sets of values agree well with each other, but his final value for $v = 30{,}074 \cdot 10^9$ cm/sec agrees well with a very recent determination by Klemencic, $v = 30{,}15 \cdot 10^9$. The observer proposes investigating the question, whether errors of former investigations are due chiefly to the electro-magnetic or to the electro-static measurements involved. M. B. S.

THE LIGHT-RATIO OF STELLAR MAGNITUDES.—S.C. Chandler, Jr., (*Astron. Nachr.* **115,** 146,) in a general discussion of the light-ratio between successive stellar magnitudes, used for magnitudes less than the sixth, the results of Seidel, Zöllner, Peirce, Wolf, Pickering and Pritchard, for comparison with the scales of the *Uranometria Nova* and the *Durchmusterung*, and concludes first that an inspection of results is forcibly impressive of the imperfect condition of instrumental photometry; secondly, that between the second and the sixth magnitudes the universally adopted scale is practically as iso-photometrical as could have been established by the most elaborate instrumental means; third, that the value of log. ρ here resulting is 0·350. From a discussion of telescopic magnitudes, he also finds the mean between the scales of Ceraski and Rosen to be 0·365. The author hence concludes that the evidence points to a uniform light-ratio in the neighborhood of 0·360. This makes the base itself 2·29 as distinguished from the old value 2·51.

M. B. S.

THE ATMOSPHERIC LINES.—M. Cornu (*Phil. Mag.*, **22,** No. 138,) has devised and carried into effect an elegant and successful method of distinguishing between spectral lines of solar and terrestrial origin. This method is founded on the principle of the displacement of the spectral lines of a source of light in absolute or relative motion. Applied to the light emitted by the solar disc at the two extremities of an equatorial diameter, and taking the velocity of a point on the solar equator as two kilometres per second, the velocity of light as 300,000 kilometres per second, we shall have a variation of wave length equal to

$$\Delta\lambda = \pm\lambda \times \frac{2}{300{,}000} = \pm\frac{\lambda}{150{,}000}$$

+ or — according as the radiation is taken from the eastern or western end of the solar equator. The double displacement is, therefore, readily shown to be $\frac{1}{75}$ of the distance between the two D lines, for that region of the spectrum. Small as the total displacement is, it may become sensible with a Rowland grating for almost all points of the solar contour; even for those far from the maximum separation.

The experimental method consists in alternately throwing upon the slit of the spectroscope the images of the two opposite extremities of the solar equator. This is effected by oscillating a condensing lens, which forms in

the plane of the slit a sharp image of the solar disc. Now one edge, now the other, forms the spectrum, and solar lines are distinguished from telluric at a glance; the former being relative to any fixed point on the cross wires displaced, while the latter remain stationary. M. Cornu gives a special study of the telluric bands α, *B* and *A*.

Prof. E. C. Pickering (*Science*, January 7, 1887,) had also suggested to Prof. Rowland the feasibility of photographing the spectra of opposite limbs, the image of the sun being formed on the slit by a double image prism, a method that seems to possess several advantages. M. B. S.

Motion given to the Air by the Wing of a Bird. (*Comptes Rendus*, **103.** 1886.)—Observation has shown that certain birds can rise without preliminary impulse, with the axis of the body nearly vertical, and consequently giving their wings a nearly horizontal motion. The wing must then produce at this initial instant of flight a violent current of descending air, the reaction of which coming up from below will raise the bird's body. It is known, moreover, that if a bird's wing or fan is vibrated in the air, the air escapes lengthwise of the surface striking it. M. Müller attributes this effect to the fact, that a stratum of air is compressed against the surface of the moving wing, flows rapidly in the direction of the flexible edge of the wing, and carries after it a certain mass of air, communicating to it its velocity. The principle would be like that employed for ventilation, when air is carried in a long conduit, by injecting a jet of air with great force into it. Experiment has shown that under these conditions, in the same section of the injector-tube, the suction is stronger if the jet is spread in a thin sheet than if it is of a cylindrical form. The explanation of this is that in the first case the surface for friction is more extended. It has also been noted that the suction of the air is more intense when the injection is intermitted than when it is continuous. Now these two conditions, flattening of the stratum of air in motion and intermittance of the jet, are combined in the movement of the air, which flows at a tangent to the plane of a bird's wing. Finally, if a thin layer of air escapes from the back-edge of the wing, and parallel to the plane of it, a reaction also parallel to this plane will be produced along the front-edge, where the bony portions in relief prevent the air from escaping; it is this reaction, which makes the bird advance. To demonstrate the reality of these phenomena, M. Müller has arranged little contrivances, by which the loosening of a spring gave to a wing or a flexible plane, a fluttering on a small scale. He then studied the movements, which were produced in the air (by making this visible) in daylight by means of smoke, following Tyndall's example, or at night by phosphorescent vapors. The existence of the compressed sheet of air, escaping along the thin edge of the wing, was revealed to him by the following experiment. In front of this flexible edge, a thread of cotton is burned, which sends up a thin, vertical column of smoke into the quiet air. The plane is lowered, a transparent aperture is produced in the column of smoke by the layer of air which escapes under the wing; this stratum draws after it, at right angles with its original direction, the column of smoke, which continues to form under it. The layer of air which escapes,

following the plane of the wing, is scarcely ten millimetres or fifteen millimetres thick; the faster the motion moreover, the thicker the air is. This current, on penetrating the motionless air, encounters resistance and produces whirls, which increase in size, in proportion to the distance from their source, the edge of the wing; they attained in the experience of the author a decimetre in diameter. These whirls, which form one after another on both sides of the current of air, have an opposite rotation on the two sides. To render them visible, the author let the smoke or phosphorescent vapors accumulate under the wing, which he suddenly lowered, seeing then the two series of whirls form, grow and multiply, speeding-off and turning in opposite directions on the two sides of a plane in continuation of the wing surface. Finally, to show that a projection on the edge of the moving plane holds back the air and prevents its escape, he made use of a simple fan of folded paper, and after having proved that a certain rapidity of fanning produces a draught, he edged the fan with a narrow band of paper at right angles with its surface. By influence of this slight projection, which holds back the air, the breeze is stopped. To recall it, more rapid movement must be given to the fan; the layer of compressed air is then increased in volume and escapes over the barrier. C.

ELECTRIC CONDUCTIBILITY OF GASES AND VAPORS.—Many theories relative to electrical machines and atmospheric electricity are still founded upon the supposition that damp air is a conductor, or that gases and vapors can become electrified by friction, although it has repeatedly been proved that they are very poor conductors. M. Jean Luvini, from the results of his experiments and those of other investigators, has arrived at the conclusion that gases and vapors under any pressure whatever and at all temperatures are perfect insulators, and that they cannot be electrified by friction either among themselves or with solid bodies or liquids. M. Luvini applied his tests to air saturated with steam at different temperatures from 16° to 100° C.; hydrogen and carbonic acid not dried, but in the state in which they come from the bath which produces them; air heated by live coals or by candle flame, smoke from an extinguished candle, fumes of sugar, chamomile, incense, mercurial vapor at 100° C., the fumes of sal-ammoniac, etc. In no case was there the least evidence of conductibility. It is generally believed that gases greatly rarefied, or at very high temperatures, are conductors. This error arises from confounding the resistance to disruptive discharge with the resistance to conductive discharge. Masson found that with equal potential the distance of disruptive discharge is twelve or thirteen times greater in air than in water. Thus, the resistance of water to disruptive discharge is greater than that of air; but who would conclude from this that air is a better conductor than water? C.

MECHANICS.

THE RESULTS OF A MATHEMATICAL INVESTIGATION OF THE LIMITATIONS OF THE EXPANSION OF STEAM, by Prof. William Dennis Marks, of the University of Pennsylvania, can be epitomized as follows:

We cannot expect, under the most favorable circumstances, to reach an economy which will surpass but very slightly one pound of coal per indicated horse-power per hour.

This would place eighteen per cent. of the heat in coal as the extreme limit of its utilization. The condensation of steam occurs during its admission to the cylinder, and in some cases is surprisingly great.

The law of this condensation is as follows:

The condensation of the steam in the cylinder is proportional to—

(1.) The difference of temperatures of the steam at the point of cut-off. and while being exhausted.

(2.) To the area of cast iron exposed to the entering steam up to the point of cut-off.

(3.) To the time of exposure of the interior surface of the steam cylinder to the exhaust steam.

(4.) The condensation is reduced by compression, subject to the same laws, but this is usually quite a small quantity.

The initial condensation of steam is due principally to the piston and cylinder heads.

The equilateral hyperbola approximates quite as closely as any other curve to the curve of expansion of steam in engines not embarrassed by a sluggish valve motion.

Compression will save some vaporous steam, but will not largely diminish the initial condensation because of its short duration.

Superheating is the most efficient expedient for economizing coal.

The steam jacket is not so efficient as is ordinarily assumed.

Slide valves are frequently the cause of large and unlocated losses.

The valves and pistons of steam engines are rarely steam-tight.

With properly designed compounded cylinders, the ultimate expansion of the steam is a function of the ratio of the two cylinders.

The saving in compound engines is due to lesser initial condensation in the non-condensing cylinder.

From the physical properties of iron arises the necessity of, and advantage of, compound engines.

The beneficial effects of superheating, steam-jacketing and compounding, are more apparent in small than large engines.

The most economic ratio of stroke to diameter for steam cylinders is a function of the number of expansions, of the boiler pressure, of the exhaust pressure, and of the number of strokes per minute.

A large cylinder is more economical than an equal volume divided among small cylinders.

High rotative speeds demand shorter cylinders than are ordinarily used.

It is frequently, especially with high boiler pressures, the more economical to not use a condenser.

The throttling of steam, with an engine of fixed expansion and small cylinder, does not increase the consumption of coal per indicated horse-power per hour, but very slightly. W. D. M.

CHEMISTRY.

ON THE CARBONIC ACID CONTENT OF THE ATMOSPHERIC AIR. By R. Blochmann (*Ann.* **237**, 39–90).—The above paper combines a thorough comparative study of the methods employed and the experiments performed up to the present time, for the purpose of determining the amount of carbonic acid contained in the air, with an account of the modification and improvement by the author of the Dalton-Pettenkofer method for determining atmospheric carbonic acid. Considerable space is devoted to the discussion of the sources of error, to which the various methods heretofore employed are subject, and attention is called to the fact that as more refined methods came into use, and more care was taken to determine and eliminate errors of experiment, the smaller the accepted figure for the amount of CO_2 in the air became. Thus:

Periods.	Number of—		Vol. CO_2 in 10,000 Vol. Air.
	Observers.	Observations.	
1828 to 1830	1 (Saussure)	201	4·1
1830 " 1856	6	322	3·6
1856 " 1885	22	> 4,000	3·1

Of all the methods hitherto used for determining the carbon dioxide of the air, the so-called Pettenkofer method, on account of its simplicity and rapidity, was chosen by the author as the one whose imperfections could be dealt with with the greatest hope of success. The principle of the method is this, viz., into a large glass bottle containing the air to be examined, is run a measured quantity of standard baryta water. The bottle is then corked and shaken, and the baryta solution transferred to a suitable vessel, titrated with standard acid, and the excess determined. The principal sources of error are, first, the absorption of CO_2 by the baryta solution from the air of the room during the titration. Second, in washing the bottle with hot water, more or less decomposition of the glass occurs, rendering the solution more alkaline. Third, in the use of caoutchouc stoppers, which, in accordance with numerous observations, when in contact with alkaline liquids, undergo oxidation, with the liberation of carbon dioxide. The first of these difficulties has been met by the employment of a compound burette, communication between the two halves of which is effected by means of a three-way glass stop-cock. In this piece of apparatus, both the acid and the baryta solution to be determined, may be measured and titrated out of contact with the air, with the greatest accuracy. The second of the above operations has been rendered unnecessary. In order to avoid the use of caoutchouc, the neck of the bottle is fitted with a stopper, consisting of a well-fitting glass-plate, a layer of mercury, and then a layer of paraffin, the whole being bound down by a piece of sheet-rubber. Through the stopper pass two glass-tubes with stout walls, and supplied with glass stop-cocks. One of the tubes reaches to the bottom of the bottle.

The sum of the constant errors affecting any result by this method is ·10 and the probable error of a single experiment lies between + 0·025. The following table contains estimations of the carbon dioxide in the air from the laboratory garden, Königsberg:

Dates.			Bottle No. 64. Vol. CO_2 in 10 000 Vol. Air.			Bottle No. 95. Vol. CO_2 in 10,000 Vol. Air.			Joint Mean.
			I	II	Mean.	I	II	Mean.	
1885,	September	4	3·09	3·11	3·10	3·06	3·11	3·08	3·09
"	"	5	3·24	3·24	3·24	3·25	3·26	3·25	3·25
"	"	6	3·10	3·13	3·11	3·11	3·11	3·11	3·11
"	"	7	3·09	3·08	3·08	3·07	3·09	3·08	3·08
"	"	8	3·19	3·15	3·17	3·19	3·18	3·18	3·18
"	"	9	3·15	3·18	3·17	3·15	3·17	3·16	3·16
"	"	10	2·95	3·00	2·97	2·98	2·98	2·98	2·98
"	"	11	2·91	2·96	2·93	2·94	2·95	2·95	2·94
"	"	12	3·16	3·13	3·14	3·14	3·15	3·15	3·15
"	"	13	3·06	3·09	3·07	3·03	3·05	3·05	3·06
					3·10			3·10	3·10

A. G. P.

A New Reaction for the Detection of Small Quantities of Hydrocyanic Acid.—G. Vortmann (*Monatschefte*, **7**, 416,) states that Playfair's reaction of the cyanides and nitrites is an exceedingly delicate test for a cyanide or hydrocyanic acid, the resulting nitro-prusside being recognized by its reaction with sulphides. The liquid to be tested is mixed with a few drops of potassium nitrate solution, from two to four drops of ferric chloride solution, and enough dilute sulphuric acid to change to bright yellow the first formed yellow-brown color of the basic iron salt. The mixture is heated until it begins to boil, then allowed to cool, and after the separation of the excess of iron a few drops of ammonia are added; the liquid is filtered and the filtrate treated with one or two drops of a much-diluted solution of colorless ammonium sulphide. The presence of hydrocyanic acid in the liquid will now occasion a beautiful violet color, changing in a few minutes to blue, then to green and yellow. Traces of hydrocyanic acid occasion only a bluish-green color, that rapidly becomes yellowish. The limit of the reaction is put at a dilution of 1:312,500, ten cubic centimetres of liquid being used; the limit of the Prussian blue reaction is 1:50,000; that of the ammonium rhodanate 1:4,000,000. W. H. G.

A New Explosive Mixture.—A. Cavazzi (*Gazzetta Chimica Italiana*), in studying the reduction of potassium nitrate by various substances, has found that a mixture of equal parts of the nitrate and sodium hypophosphite detonates violently when heated to about the fusing point of the mixture. The experiment should be made on small quantities only, and while other proportions yield an explosive mixture, those mentioned are the best.

W. H. G.

Determination of Fat in Milk, etc. M. Kretzschmar. (*Chem. Zeitung*. 1886. 100.)—A gravimetric determination of fat in milk and other

emulsions is generally done by evaporating to dryness a weighed or measured quantity of substance in a porcelain or platinum dish, in which beforehand a layer of powdered gypsum is placed, sufficient to absorb all liquid. The dried mass is then removed from the dish by means of a suitable instrument, powdered and extracted. In a laboratory, where a large number of fat determinations are to be made, the removal of this cement like adhesive residue from off the porcelain or platinum dish, is a troublesome and time-taking operation. This difficulty of the evaporation method is obviated by the following modification: By means of a suitable ball of cotton, or similar material, a piece of tin-foil is firmly pressed into the dish so as to form a close-fitted lining. A proper quantity of powdered gypsum is then placed into the dish, and a cavity made for the reception of the milk, etc., which, after absorption by the gypsum, is evaporated without stirring. (The use of sand instead of gypsum is not admissible, as it furnishes too low results.) After evaporation the whole contents are easily removed from the dish with the tin-foil, and after cutting the latter into shreds, powdered to be, lege artis, extracted.

Hoffmeister's thin glass dishes would, perhaps, be handier, but much more expensive than this very expedient tin-foil lining. L.

Treatment of Thomas-Slag for Fertilizing Purposes. L. Blum. (*Chemiker Zeitung*. 1886. 100.)—The first experiments in applying crude Thomas-slag directly as a fertilizer having turned out satisfactorily, any chemical treatment rendering the phosphoric-acid soluble, being unnecessary, the author proposes—in order to obviate the grinding of the slag—to subject it in the molten state to a jet of steam of from two to four atmospheres pressure while it is discharged from the converter, quite similar to the preparation of slag-wool. As Thomas-slag always contains a large excess of lime, in this case, however, no slag-wool is obtained, but a fine, fibrous powder requiring no further treatment. By the chemical action of steam upon the molten slag, metallic granules are oxidized, and the sulphur of the slag is partly eliminated. L.

Notes on Russian Petroleum.—(*Continued.*)—See this Journal **123**, 76.—Three forms of stills are in use in the refineries of the Baku district, viz.: the upright cylindrical still of wrought iron, the so-called wagon-body still, and the horizontal cylindrical still. The last of these forms is almost exclusively used in the larger refineries. A large number of these horizontal cylindrical stills are generally placed side by side, and so are fed with crude naphtha from a common pipe, which runs along in front of the row, with short vertical branches delivering the oil into each still. The hot-oil residues are taken off from the lowest part of the still by wide pipes, which connect with a common horizontally placed pipe. And, as by the breaking of these pipes, filled with highly-heated residual-oils, dangerous fires could readily ensue, which would make it impossible to get to the connections of these pipes with the stills to close the valves from the outside, the valves are placed *inside* the still, while the valve stems reach through the still and project above, where they are easily accessible. In the Nobel refinery, an open trench, through which water is kept continuously running, is laid along before

the row of stills, so that all dripping oil is carried away at once, and the ground and space near the stills does not become saturated with oil—a most fruitful source of danger.

Quite frequently, *dephlegmators*, or so-called "separators," are interposed between the helmet of the still and the condenser, so that the vapors of the burning-oil distillate are separated from the lubricating-oils mechanically drawn over with them. These condensed, heavier vapors either flow back by a separate connection into the still, or into a distinct receptacle, and afterwards serve for the manufacture of what is called "solar-oil," a grade of illuminating-oil. One of the characteristic features of the Baku petroleum distilling is the almost exclusive use made of "astatki," or oil-residue, for fuel. The great scarcity of wood or coal in that country caused both crude-oil and its distillation products to be used for fuel from the beginning of the operations there. Prof. Engler states that the heating value of these residues is almost double that of bituminous coal, and that ordinary burners using this "astatki" can evaporate twelve times the weight of water compared to that of fuel used, while the best burners, with one kilo of "astatki," can evaporate fourteen to fifteen kilos of water. Three to four parts by weight of these residual-oils used as fuel will suffice to carry on the distillation of 100 parts of crude-oil for the burning-oil fraction.

The burner in which these residues are used, or "forsunka," as it is called, locally, has various forms. The essential feature in all the forms is the atomizing of the oil by super-heated steam, and the burning of it in this condition. The temperatures attained are, in some cases, so high that wrought-iron is fused thereby, so that the bottoms of stills, heat-pipes, etc., must be protected from immediate contact with the flame of the "forsunka."

Of course, this "astatki" serves as the material for the manufacture of lubricating-oils, but the amounts obtained are so large that the greater part is still used for fuel, so that not only is all distilling done with the aid of it, but it is used throughout the entire district for steam-generating both for stationary-engines and for ships and locomotives. Thus, the steamships of the Caspian Sea, and, in part, those of the Black Sea and of the river Volga, the locomotives of the Trans-Caucasian, the Trans-Caspian, and other Russian railroads, make use of this "astatki" as fuel.

Although the results vary somewhat, the percentages of the several products may be given as follows:

	Boiling Point.	*Per Cent.*
Benzine (with gasoline), ...	— to 150° C.	5 to 7
Kerosine I (burning-oil), ...	150° to 270° C.	27 to 33
Kerosine II (solar-oil), ...	270° to 300° C.	5 to 8
Residues, ...	300° to —	50 to 60

These residues, which make up one-half or more of the total crude-oil distilled, show a sp. gr. of 0·900 to 0·910, and, although, as compared with American petroleum residues, they show extremely small amounts of paraffine, they yield on distillation a considerable amount of oils, which, on account of their viscosity, their low cold-test and high fire-test, are among the best

mineral lubricants known. The manufacture of lubricating-oils is, however, just beginning to develop. Taking the production of crude-oil in 1885, at 16·4 million metric centners (11·714286 barrels), and assuming the production of fifty-six per cent. of residues, we would have 9·2 million metric centners (6·571428 barrels) residues. If 1,000,000 metric centners of this be allowed for the needs of the refineries for fuel, steam-generating, etc., we still have 8·2 million metric centners (5·857143 barrels), for the lubricating-oil manufacture. This yields on an average forty per cent. of lubricating-oil, which would amount, therefore, to over 3,000,000 metric centners (2·142857 barrels). But the lubricating-oil production of Baku and the surrounding district, does not yet amount to the tenth of this, being in 1885 only 260,000 metric centners (185,714 barrels.)

The amount of residues needed for fuel in the distillation of lubricating-oils, amounts to twenty per cent. of the charge, instead of the three or four per cent. mentioned before as necessary for the burning-oil distillation.

In connection with the transport and the marketing of the oil, the Nobel Brothers, as said before, have been the most active. They had, in 1884, for use on the Caspian Sea and the Volga, a flotilla of sixty-nine ships, one-third of the number being steamers, and for railroad traffic about 2,000 tank-cars. They had, moreover, extensive storage tanks at all prominent points in Southern Russia, and even as far North as St. Petersburg and Riga. Some 900 tank-cars are also in use on the line of road between Baku and Batoum, on the Black Sea, and a pipe-line for this distance is projected.

Tank-steamers for the transport of Russian-oil in bulk between St. Petersburg and Stettin and Lübeck, in Germany, are now building. S. P. S.

Heating and Smelting Experiments with Water-Gas.—H. Rösler and M. Ehrlich publish very interesting results on this subject in the *Sprechsaal*, 1886, p. 747, and reported in *Dingler's Polytech. Journal*, **263**, 108. The experiments in question were made at the parting and refining works at Frankfort-on-the-Main. It was found that water-gas made in a Wilson generator, and averaging in volumes: eighteen carbon-monoxide, ten hydrogen, sixty-eight nitrogen, four carbon-dioxide, was quite serviceable for boiler-heating, but unfit for smelting purposes. The melting temperature of silver could hardly be reached, the gas having lost its generating temperature of 400° C. by the transit from the generator to the furnace. By utilizing this temperature and heating the air of combustion, the ordinary smelting operations could be performed; but, nevertheless, the use of this Wilson generator was discontinued, because the gas was not cheaper than other fuel for boiler-heating.

Since 1885, the refining works use water-gas furnished by the neighboring Frankfort gas-works, at the rate of six pfennige per cubic meter, or 39·1 cents per 1,000 cubic feet. This gas averages: thirty-six carbon-monoxide, fifty-one hydrogen, seven nitrogen, four carbon-dioxide. It is not stated by what process this gas is manufactured. In composition, it is identical with the Lowe gas. This gas is still too expensive for all crude purposes; it is, therefore, only used in melting gold, silver and their alloys; fluxes and pigments for the decoration of china, and all purely laboratory work.

This water-gas was compared with the rich illuminating-gas of the Frankfort gas-works, and the leaner gas of the English company at the same city. The burners used were identical.

(1.) A copper vessel, filled with water, was heated from 15° to 100° C., under identical conditions. It took ten cubic metres of water-gas against four cubic metres of Frankfort rich gas, and five cubic metres of the English company's gas.

(2.) Equal weights of two kinds of flux for enamelling colors were melted under identical conditions, in a Perot furnace. The cost of the gas in each operation was M. 4·60 and M. 6·50 for water-gas, against M. 19·6 and M. 26·8 for the rich Frankfort gas.

(3.) Equal quantities of fine silver and copper were melted with the two gases in the same furnace. It required of water-gas M. 4·30 and M. 5·70, of rich illuminating-gas M. 16·7 and M. 21·7. By using water-gas, therefore, one can accomplish all boiling, heating or evaporating for *one-half* the money, all melting for about *one-quarter* the money, against the use of illuminating-gas. (It will be seen that this is only the result of the difference in the price of the two gases. For from Experiment 1, it follows that the pyrometric value of the coal-gas is 2·5 times as high as that of the water-gas.

G. A. K.

ALBANO BRANDO, described in the *Zeitschrift für Mineral. und Krystallogr.* **12,** 234, artificial crystals of Nickelantimonide, which occurred in the hearth of furnaces used for melting antimonial worklead, at the works of "Mechernich." These crystals are identical with the mineral *Beithauptite* They are 5–25 mm. long, 0·1 to 0·5 mm. thick, color between steel-blue and copper-red, adamantine lustre. After digesting the crystals in hydrochloric acid for removing adhering impurities, they contain 60·89 per cent. Sb, 30·01 Ni, 0·11 Co, 5·39 Pb, 1·17 Cu, 1·24 Fe. Total, 98·81. Spec. Gr. 8·21. The crystals are holohedral *hexagonal* combinations of ∞ P. $\frac{2}{3}$ P. 2 P.

J. HOCKAUF, *ibid*, page 240, gives a crystallographic and chemical study of *Botryogen*. This mineral occurs as secondary product in the copper mines of Fahlun, Sweden, and was described by Berzelius, 1815. This ferri-sulphate occurs in botryoidal or grape-shaped masses. The berries are one-half centimetre diameter, and are made up of radially arranged crystals. The surface is covered by a mealy, whitish yellow crust, but underneath this the small crystals are transparent, and of hyacinth-red color. The author inclines toward the assumption of the asymmetric system instead of the monosymmetric system of previous authors.

The analyses lead to the formula—$Mg\,Fe\,S^2\,O^8 + Fe^2\,S^2\,O^9 + 18\,H^2O$, whilst Berzelius gave $\overset{II}{Fe^2}\,S^2\,O^9 + 3\,\overset{III}{Fe^2}\,S^2O^9 + 36\,H^2O$, neglecting magnesium, calcium, and manganese in the calculation.

GEO. A. KOENIG, Philadelphia, shows in a preliminary paper (*Proceedings Academy Natural Sciences*, Philadelphia, 1886, p. 355), that the so-called *Schorlomite*, of Magnet Cove, Ark., is to be considered as a melanite garnet, in which titanium replaces both ferric iron and silicon. The presence of an oxide which reduces potassium permanganate has been overlooked by other

analysts or attributed to ferrous iron, but here it is shown that if this reducing power be attributed to titanic sesqui-oxide, the formula becomes that of a melanite, and the fact that the percentage of titanium varies from seventeen to twenty-seven per cent. becomes intelligible. Thus the composition of one sample of the mineral is 25·80 $Si O^2$, 12·46 $Ti O^2$, 4·44 $Ti^2 O^3$, 1·00 $Al^2 O^3$, 23·20 $Fe^2 O^3$, 31·4 Ca O., 1·22 Mg O., 0·46, Mn O. Total, 99·98.

G. A. K.

THE GREAT VALUE OF ISOCHROMATIC PLATES in micro-photography has been demonstrated by Dr. Crookshank, who exhibited to the Royal Microscopical Society of London, micro-photographs of bacteria, obtained without staining the objects with aniline as in Koch's process, and he has still more recently exhibited a photograph showing the flagella of a vibrio. C. F. H.

A NOVEL AND VALUABLE APPLICATION OF PHOTOGRAPHY has been made by the Century Company, combining the complete preservation of valuable copy, against accidental loss or injury by fire or otherwise, with the greatest convenience in storage and handling. Over 25,000 sheets of copy of a work on its way through the press with interlineations, corrections and additions, have been photographed on a reduced scale, of only 1¼ x 2 inches to the page, but easily legible upon magnification. C. F. H.

IT WAS PREDICTED by Sir David Brewster, that a camera with only a pin-hole and without lenses would become the favorite instrument of the photographer, if photographic processes should become sufficiently sensitive to permit. Now that gelatine plates afford all needed sensitiveness, Capt. Colson, of Paris, has recently tested the method, and, in a brochure embodying his results, gives as an illustration, a photograph of the "Dome des Invalides" with an aperture of ·3 of a millimetre, and the plate 0·13 metres from the aperture, with an exposure of twenty seconds. The picture as a general view of the subject has a value, but will hardly impress favorably persons accustomed to the exquisite details and definition of modern photographs. Whilst in some cases absence of distortion and width of angle might give it a value, there would be other optical defects arising from illumination of bright points or small surfaces. C. F. H.

THE VAPOR DENSITY OF ZINC.—Justus Menshing and Victor Meyer (*Berl. Ber.* 3,295) have determined the vapor density of zinc, using the porcelain apparatus described by V. and C. Meyer (*loc. cit.* **12.**, 1,112) in a furnace capable of producing a temperature about 1,400° C. The apparatus was filled with pure nitrogen, and the vaporization of the zinc took place quickly and regularly. In one experiment, in which the temperature was not raised to the full power of the furnace, the density found was 2·41; in another, conducted at the highest attainable temperature, the density was 2·36. These figures assign the value Zn for the molecular formula of zinc vapor; theory would require the number 2·25. The three metals, whose vapor densities have been determined, (mercury, cadmium and zinc) have, in the gaseous state, molecules containing but a single atom. W. H. G.

Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, February 16, 1887.*]

HALL OF THE INSTITUTE, February 16, 1887.

MR. JOSEPH M. WILSON, President, in the Chair.

Present, 142 members and 115 visitors.

New members elected since the last report, ten.

MR. JOHN JACOB HALTZAPFEL, of London, on the recommendation of the Board of Managers, was elected a corresponding member.

On behalf of the Committee on Meteorology, the Secretary made an oral report of the committee's work, in reference to the establishment of a "State Weather Service." In connection with this work, an Act had been drafted which contemplated financial aid from the state in carrying on the proposed service. The following is the text of the Act referred to, which, it is hoped, by the committee, will receive the favorable consideration of the Legislature, viz :

AN ACT

To establish a STATE WEATHER SERVICE in this Commonwealth, for the purpose of increasing the efficiency of the United States Signal Service, by disseminating more speedily and thoroughly the weather forecasts, storm and frost warnings, for the benefit of the citizens of this state, and for the purpose of establishing and maintaining in each county thereof meteorological stations for the collection of climatic data, and making an appropriation therefor.

WHEREAS, By reason of the limited facilities of the United States Signal Service, the practical benefits to be derived from the weather forecasts, storm and frost warnings, issued from the Chief Signal Office, at Washington, D. C., are greatly restricted, especially in the agricultural districts, by the want of proper means for disseminating these official reports promptly; and,

WHEREAS, By the organization of a STATE WEATHER SERVICE, co-operating with the United States Signal Service, the weather forecasts, storm and frost warnings hitherto accessible only to a very small proportion of our people, may be much more rapidly and widely disseminated throughout the state, whereby the value of the same to the agricultural and other interests will be largely increased; and,

WHEREAS, The climatology of the state has never been observed and recorded in as thorough and systematic a manner as is necessary for the best promotion of the various industries: and

WHEREAS, The STATE WEATHER SERVICE, already established and maintained by state aid in Alabama, Illinois, Indiana, Iowa, Minnesota, Mississippi, Missouri, Nebraska, Massachusetts, Ohio, Tennessee and others, co-operating with the United States Signal Service, have proved of great value to their citizens, especially to the farmers, who stand most in need of prompt and accurate information of anticipated climatic changes for the protection of their crops, and who are most directly benefited thereby; and,

WHEREAS—At the request of the Chief Signal Officer, the FRANKLIN INSTITUTE, of the State of Pennsylvania, for the Promotion of the Mechanic Arts, has proposed a plan for the organization of an efficient WEATHER SERVICE for this state—therefore,

Be it enacted, etc.

Section 1. That the Secretary of Internal Affairs of this Commonwealth be and is hereby authorized and directed to name and appoint, on the recommendation of the FRANKLIN INSTITUTE, of the State of Pennsylvania, for the Promotion of the Mechanic Arts, one, or more, competent observers in each county of the state, for the purpose of taking, recording and transmitting observations of the atmospheric pressure, temperature, humidity, rainfall, wind and other meteorological phenomena occurring in their respective localities; and the Secretary of Internal Affairs is hereby authorized and directed to purchase and furnish to each of said observers, such standard meteorological instruments as are used by the United States Signal Service, and such signal flags and other necessary equipments, and such necessary clerical expenses as shall be designated and approved by the said FRANKLIN INSTITUTE.

Sec. 2. The central office of the STATE WEATHER SERVICE shall be located in the City of Philadelphia, at which the weather forecasts and warnings of the U. S. Signal Service shall be received, and from which the same shall be disseminated throughout the state, and to which the STATE WEATHER SERVICE observers shall send their observations.

Sec. 3. The management of the work of the Pennsylvania STATE WEATHER SERVICE shall be under the supervision and direction of the FRANKLIN INSTITUTE of the State of Pennsylvania, for the Promotion of the Mechanic Arts and the said FRANKLIN INSTITUTE is hereby authorized to make such use of the information thus collected by the publication of a Weather Review, and by other proper means, as will best promote the usefulness of the service to the citizens of the State. And the services of the said FRANKLIN INSTITUTE, and of the said observers of the STATE WEATHER SERVICE shall be made without compensation.

Sec. 4. The sum of *three thousand dollars* be and the same is hereby appropriated for the purpose of carrying into effect the provisions of this Act, to be expended on the warrant of the Secretary of Internal Affairs drawn upon the State Treasurer.

The Committee has likewise proposed to the Pennsylvania Railroad Company, a plan for the considerable extension and improvement of the present method of disseminating the daily weather reports along the lines of this railroad. To this proposition, which involves the display of the signal flags at stations receiving the weather bulletin, no definite response has yet been received.

The LaCour-Delany Committee made a report of progress and was continued.

THE PRESIDENT announced the following appointments on committees for the current year:

STANDING COMMITTEES OF THE FRANKLIN INSTITUTE FOR THE YEAR 1887.

Library.	*Minerals.*	*Models.*
Charles Bullock,	Clarence S. Bement,	Edward Brown,
J. Howard Gibson,	Persifor Frazer,	John H. Cooper,
Frederick Graff,	F. A. Genth,	C. Chabot,
Geo. A. Koenig,	Edwin J. Houston,	L. L. Cheney,
S. H. Needles,	George A. Koenig,	N. H. Edgerton,
Isaac Norris, Jr.,	Otto Lüthy,	John Goehring,
John C. Trautwine, Jr.	E. F. Moody,	Morris L. Orum,
Chas. E. Ronaldson,	H. Pemberton, Jr.,	Chas. J. Shain,
Wm. P. Tatham,	Theo. D. Rand,	John J. Weaver,
Lewis S. Ware.	Wm. H. Wahl.	S. Lloyd Wiegand.

Arts and Manufactures.	*Meteorology.*	*Meetings.*
J. Sellers Bancroft,	Lorin Blodget,	Hugo Bilgram,
George Burnham,	Charles M. Cresson,	A. B. Burk,
George V. Cresson,	Edwin J. Houston,	Geo. V. Cresson,
Cyrus Chambers, Jr.,	Isaac Norris, Jr.,	G. M. Eldridge,
Wm. Helme,	Alex. E. Outerbridge, Jr.,	Dr. Persifor Frazer.
Wm. B. Le Van,	J. S. W. Phillips,	Fred'k Graff,
Alfred Mellor,	Joshua Pusey,	Henry R. Heyl,
Henry Pemberton,	M. B. Snyder,	Washington Jones,
Wm. Vollmer,	Wm. P. Tatham,	G. H. Perkins,
John J. Weaver.	Wm. H. Wahl.	Chas. J. Shain,

Mr. PEDRO G. SALOM, of Philadelphia, read a paper on "The Julien System of Electric Transmission," which, with discussion thereon, has been referred to the Committee on Publications.

Mr. FRED'K E. IVES, of Philadelphia, read a paper on "Heat-Photography," embracing the results of some further researches in photographing with phosphorescent substances. The paper appears in this impression of the JOURNAL.

Mr. CARL HERING, of Philadelphia, by request, described and illustrated by experiment, the principle of the electric-lighting system of ZIPPERNOWSKI–NERI, in which alternating currents of high tension are converted, by an induction apparatus, into currents of low tension, suitable for incandescent lighting.

Mr. CHARLES RICHARDSON, of Philadelphia, described an ingenious modification of a dynamo-electric machine, which was used in this experiment, by which it was made practicable to obtain from it either direct or alternating currents. The subject was referred for publication.

THE PRESIDENT expressed the gratification of the INSTITUTE, on account of the presence at the meeting, of the members of the NATIONAL ELECTRIC LIGHT ASSOCIATION, now holding its sessions in Philadelphia, and extended to the Association a cordial welcome to the INSTITUTE. PRESIDENT MARSHALL, of the Association, responded with appropriate remarks.

The SECRETARY'S REPORT embraced some comments on the alleged successful demonstration, in London, of the claims of MR. CASTNER, for the cheap production of the metals of the alkalis; and on the present general adoption throughout the United States of the Sellers, or United States standard of screw threads, recommended for general adoption by the FRANKLIN INSTITUTE, in 1864. The consideration of this subject was called forth by a letter lately received from the SOCIETY OF GERMAN ENGINEERS, of Berlin, inquiring for information, and referring to an article published in a recent impression of (London) *Engineering*, in which the system of Sellers (now known as the FRANKLIN INSTITUTE, or United States Standard) was asserted to have failed in practice, and to have been abandoned. The correspondence on this subject has been approved for publication, and will shortly appear in the JOURNAL.

Adjourned. WM. H. WAHL, *Secretary*.

THE "NOVELTIES" EXHIBITION OF THE FRANKLIN INSTITUTE, 1885.

ABSTRACTS OF REPORTS OF THE JUDGES.

(*Continued from Vol. CXXIII, page 88.*)

GROUP 12*b*.—GAS APPARATUS, INCLUDING HEATING AND COOKING STOVES, BURNERS FOR ILLUMINATION, ETC., NATURAL GAS BURNERS AND FURNACES.

Judges:—Lemuel Stephens, *Chm.*, Luther N. Cheney, W. H. Blake, M. D., Moses G. Wilder, Joseph Bond, Jr., Joseph Zentmayer.

The Committee of Judges appointed to examine the objects classified as group 12*b*, respectfully report as follows:—

THE FERRACUTE MACHINE CO., BRIDGETON, N. J.

Egg-Cooker with Gas-Stove.—The gas stove requires no special notice, any other mode of applying heat may be substituted.

The egg-boiler consists of a moon-shaped disc resting upon a spiral spring, which is supported by a central post. Around the outer rim of the disc are holes in which the eggs are placed, and the "boiler" is then put in a vessel containing boiling water.

Pressure upon a knob at the top of the post then depresses the disc below the surface of the water, where it is secured by a trip-catch. Above the disc is a bar or yoke, pivoted upon the central post, from one end of which depends a bucket, having a small hole in its bottom, which serves to gradually fill the bucket with water. Upon the opposite end of the yoke is a counterpoise, which slides upon a registered scale; its distance from the centre regulates the pressure of the bucket upon the water, and determines the length of time required to fill it, whether one, two, or more minutes. When the bucket is filled, its weight overcomes that of the counterpoise, the yoke is tilted, the trip-catch released, and the spring lifts the disc and eggs out of the water; at the same time the bucket being hung a little out of centre, tips, and empties itself, and the "boiler" is ready to be refilled.

This automatically acting contrivance is ingenious, and secures uniformity and exactness in boiling eggs.— (*Honorable Mention.*)

J. M. FOSTER.

Lighting Beacons and Buoys.—The committee have examined the Foster system of lighting beacons and buoys, with compressed gas, and were impressed with the importance of this invention as affording the means of guiding the mariner, and saving him from shipwreck in darkness and storm, and thus contributing largely to the welfare of mankind. If this invention could claim the merit of novelty or originality, its merit would go far to establish Mr. Foster's claim to the highest award within the gift of the INSTITUTE.

The depth to which the more slender cylinders of Mr. Foster descend into the water, and the great weight attached to the bottom, insures steadiness of the light in a storm.

Foster's Compressed Gas Compressor, and Foster's High Pressure Gas Governor, are both perfectly effective, and contain features of originality worthy of recognition. On account of these valuable improvements in the Foster system, your committee would recommend the award of— (*A Bronze Medal.*)

GOODWIN'S GAS STOVE AND METER COMPANY.

Goodwin's Gas Stove and Meter.—Mr. W. W. Goodwin exhibited a great variety of gas apparatus, used advantageously for heating, cooking and lighting. The corrugated copper reflector that can be used in the roasting ovens, is specially adapted for heating the room and diffusing a cheerful light.

A small pipe leading into the flue carries off the products of combustion and keeps the air odorless and pure. The cooking stoves and ranges presented were of many sizes, adapted to the wants of private families and largest hotels, on which every variety of roasting, baking and boiling may be carried on simultaneously, without any trouble in regulating the heat, and without emitting odors.

The comfort, neatness and economy of cooking and heating by gas are very fully attested by the certificate of those who have used the Goodwin's apparatus, and the exhibition to the committee of the many appliances in gas, for household economy, impresses them most favorably. The cheerful light and heat of an open fire were beautifully illustrated by an incandescent bed of asbestos or pumice stone.

Mr. Goodwin presented tabulated experiments in cooking a great variety of articles of food on a Peerless coal range, and one on a Sun-Dial gas stove, by which a saving in cost of fuel, in time required, and in loss by waste in cooking, is shown in favor of gas.

Mr. Goodwin states that from the average of his experiments, he finds that meat roasted by coal fire loses thirty-three and one-third per cent., while the same cooked by gas, loses only fourteen per cent., and retains its juices and flavor more perfectly. This estimate of the saving by gas seems to us excessive, but an actual saving to some extent is undoubted.

For the extensive and varied display of useful, economical and ornamental apparatus for the consumption of gas—

(*A Silver Medal.*)

THE GLOBE MANUFACTURING COMPANY.

Globe Gas Toaster and Stove.—A removable plate of planished iron or copper, supported on a burner and adapted to give great heat and no smoke. The bread to be toasted lies upon wires close

to the copper plate. When used upon a Bunsen or other heating burner, it operates nicely, and is a very handy little appliance.

(*Honorable Mention.*)

HALL & CARPENTER, PHILADELPHIA.

The Retort Gas Soldering Iron Furnace.—This furnace consuming ten feet of gas per hour, it is said, will thoroughly heat two two-pound irons in four minutes, and will keep the irons hot, consuming six feet of gas per hour.

This furnace can be run with gas cheaper than a furnace heated with charcoal. It is much cleaner, more convenient and safer; it is always ready, being extinguished and lighted in an instant.

(*Honorable Mention.*)

Your Committee on Gas Utilizing Apparatus have to report the following tests of gas burners, together with their recommendations based in each case upon tests and examinations of the burners.

ADOLPH WASSERMAN, PHILADELPHIA, PA.

Wasserman's Regenerative Gas-Lamp.—This is essentially an argand burner, having a circular flame, the air being admitted as in the common argand. One current passing up centrally, supplies oxygen to the interior of the flame; another current passes up upon the outside, and supplies oxygen to the exterior surface; this last current is deflected just at the bottom of the flame by a circular sheet metal shell, which surrounds the burner, so that the air is brought more in contact with the flame than with the common burner of the argand type.

In the centre of the burner, springing upward from the base, is a metal pipe, which expands toward the top into a hollow cone of considerable size, and which reaches the top of the flame. This cone is surrounded by a shell of porcelain, or other heat-resisting material. The flame, passing up outside of this cone, is not in contact with it, being of a larger diameter, but the heat of the flame is such as to raise the surface of the cone to a high temperature, and the ascending current of air, which rises from the base of the burner, freely in contact with the cone, is heated as it rises. The cone also gives the air a direction toward the surface of the

flame, and thus the combustion of gas takes place at a higher temperature and produces a higher degree of incandescence.

The burner is adapted to the fixtures in ordinary use, and requires no especial training or care to secure good results. Our tests, made October 26, 1885, gave the following results:

City gas this day gave	16·20 candles.
Candles per foot of gas,	3·20

TEST NO. 1.

Gas burned per hour,	10·5 cubic feet.
Candle-power,	38·06
Candles per foot of gas,	3·62

TEST NO. 2.

Gas burned per hour.	9 cubic feet.
Candle-power,	38·95
Candles per foot of gas,	4·32

In view of the fact that this comparatively simple burner shows an efficiency equal to that of Sugg's four-ring argand burner, which consumes ninety-five feet of sixteen-candle gas per hour, we would recommend the award of the Bronze Medal of the FRANKLIN INSTITUTE to Mr. Wasserman, with the diploma of the INSTITUTE for his invention.

KITSON & CO., PHILADELPHIA, PA.

Albo-Carbon Gas-Lamp.—This lamp, shown in a variety of sizes during the Exhibition, consists of one, or a group, of gas burners, so arranged that the heat of the various flames shall be partially utilized to vaporize and render volatile a quantity of naphthalene, which is contained in a metal reservoir, forming a part of the fixtures supporting these burners. This is done by extending out over the flame, a portion of the metal structure of the fixture, so that the metal may be heated, and thus communicate its heat to the naphthalene. The gas on its way to the burners passes through the reservoir, and, becoming charged with the vapor, burns with a brilliant white light, of far greater power, than would be given by the gas itself.

The charging of the gas with the vapor of hydro-carbon, to increase its illuminating-power, is not new, and in this burner other hydro-carbon than naphthalene could be used, but the naphthalene being a solid at temperatures below 176° F., and vaporizing at

414° F. only, is more suitable for the purpose, as it can be handled and transported without danger.

Our tests were made upon a small fixture of one burner, because the large burners could not be tested upon our photometer, without making extensive alterations, and we were of the opinion that such changes were not necessary to determine the efficiency of the light, inasmuch as each group was made up of single lights of the same size as that tested.

Our tests made November 2, 1885, gave results as follows:

City gas candle-power,	17·25
Candles per foot of gas,	3·45
TEST NO. 1.	
Gas burned per hour,	4·80 feet.
Candle-power,	29·70
Candles per foot of gas,	6·18
TEST NO. 2.	
Gas burned per hour,	4·95 feet.
Candle-power,	41·10
Candles per foot of gas,	8·33
Naphthalene consumed for 1,000 feet of gas,	2·88 pounds.
Cost of same, at twelve cents per pound, for 1,000 feet,	34·5 cents.
Cost of city gas, $1.60. Cost of carburetted gas,	$1.94·5 cents.

In view of the foregoing, your committee would recommend to Kitson & Co., for their albo-carbon gas-lamp, the award of the—

(*Bronze Medal and Diploma.*)

SIEMENS–LUNGREN GAS-LIGHT COMPANY, PHILADELPHIA, PA.

The Siemens' Regenerative Gas Lamp.—This lamp shows most strikingly the great progress that has been made in methods of gas lighting consequent upon the development of the electric light. Invented at a time when the highest efficiency attained was but little over four candles per foot of gas, almost at a single stride, Frederick Siemens raised the standard to nearly or quite ten candles per foot (with the most suitable gases for use in this lamp). In so doing he not only secured great economy in lighting large spaces, but gave improved ventilation, and also a far better quality of light.

With his long experience in the adaptation of the regenerative principle to furnaces, he brought to the problem a knowledge which gave him a comprehensive grasp of the subject in all its bearings,

and enabled him not only to produce the best gas light then known, but also to illustrate forcibly certain principles, which alone would enable us to secure the highest results in illumination by the use of gas.

It is not possible to clearly explain the construction of this lamp, without detailed drawings, but inasmuch as its form can be greatly varied, without changing the principle of its action, we think a detailed description of the lamp, tested by us, is not necessary.

The central principle on which its efficiency depends, is the heating of the air and gas intensely, before they reach the zone of combustion, by bringing them into the lamp, and to this zone, in contact with metal surfaces heated to a high degree by the waste gases which are passing away from the flame.

The flame is therefore hotter and the light more intense.

This heating or regenerative action is also cumulative, and increases with the rising temperature of the flame, until, if there were no loss by radiation and the like, the heat would increase until the entire structure would be destroyed. Practically, the heat does not increase beyond a point which the lamp endures safely. The waste gases are conducted by a metal pipe to a flue, after they have done their work in the lamp, and the air of the room is left uncontaminated with the products of combustion.

A large number of lamps are used in the public squares of this city, notably, Franklin, Rittenhouse and Logan. These squares are made far more attractive and safer than before. They are also used in many other places in lighting buildings and spaces about them.

Our tests of this lamp were made on a bar photometer, with a length of 280 inches between the lamp and our standard. Our standard was a Sugg argand burner, rated to pass five feet of gas per hour.

Horizontal Tests of Siemens' Lamp, November 3, 1885 :—

Candle-power of our Standard and City gas, . . .	17·71 candles.
Candles per foot of gas, ...	3·54

TEST NO. I.

Gas burned per hour, ...	51·18 feet.
Candle-power, ...	364·65
Candles per foot of gas, ...	7·12

TEST NO. 2.

Gas burned per hour,	51·18 feet.
Candle-power,	463·11
Candles per foot of gas,	9·04

TEST NO. 3.

Gas burned per hour,	48·00 feet.
Candle-power,	396·52
Candles per foot of gas,	8·26

All of the above tests were made at one heating of lamp.

In view of the foregoing, your committee recommended the award of the Silver Medal of the FRANKLIN INSTITUTE, to the Siemens-Lungren Company for the Siemens regenerative gas lamp, togehter with a Diploma of the INSTITUTE.

SIEMENS–LUNGREN GAS-LIGHT COMPANY, PHILADELPHIA, PA.

The Lungren Inverted Regenerative Gas-Lamp.—This lamp owes its efficiency to the heating of the air and gas which enter the flame, by means of the waste heat which is leaving the lamp. Resembling in this respect the Siemens' lamp, it has peculiarities which render it noticeable, and increase its value to a marked degree.

The flame and the illumination is all below the structure of the lamp itself, there are no shadows, and the light thrown down from the suspended lamp is entirely unobstructed. The lamp is also of a form and structure, which admits of its use in a variety of places where the Siemens' lamp could not be used so conveniently. Finally, its efficiency is much higher than that of the Siemens lamp in small and medium lamps, such as are used in lighting offices, stores and apartments of moderate dimensions. Its value for general illumination is for this reason greater.

The quality of the light for brilliance, steadiness and color is unsurpassed, and the lamp itself is simple in its construction, and of a pleasing design.

In measuring the light of the lamp, your committee found it necessary to construct a photometer for the angular measurements. Horizontal measurements were made upon the bar photometer used in testing the Siemens' lamp. The flame of this lamp being entirely below the lamp, however, the horizontal rays of light do not represent its efficiency in actual use.

The series of measurements were made as follows:

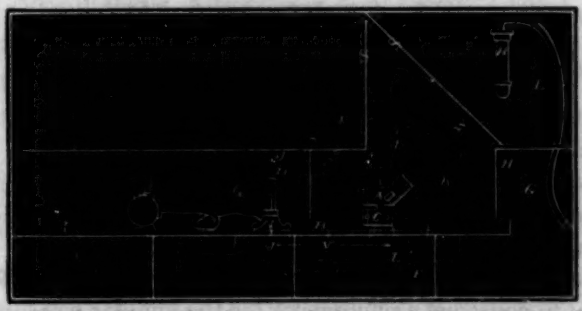
FIRST: HORIZONTAL, OCTOBER 31, 1885.

The lamp was suspended in line with the bar at the end, and its light was compared with that of the Sugg argand used in testing the candle-power of the city gas.

Candle-power of city gas,	17·69 candles.
Candles per foot of gas,	3·54
TEST NO. 1.	
Gas burned per hour,	16·44 cubic feet.
Candle-power,	124·71
Candles per foot of gas,	7·58
TEST NO. 2.	
Gas burned per hour,	17·85 cubic feet.
Candle-power,	155·84
Candles per foot of gas,	8·7
TEST NO. 3.	
Gas burned per hour,	17·25 cubic feet.
Candle-power,	157·62
Candles per foot of gas,	9·12

SECOND: ANGLE OF 45° BELOW THE HORIZONTAL LINE.

For this test we had a sight-box made, which was mounted stationary upon a bar as shown in the sketch. The screen in the sight-box *A* was placed coincident with the line *F. F.* Therefore the lights from the lamps *D* and *L* entering the sight-box at opposite ends thereof, the screen was illuminated equally when the carriage and its argand *D* were placed so that $V2 : W2 :: T : U$.



Photometer Used in Measuring Lungren's Inverted Regenerative Gas Lamp. Angle of 45° and Vertical. November 5, 1885.

A.—Sight-box stationary on photometer bar.

B.—Bar of photometer stationary on table.

C.—Wooden clamp to carry sight-box for adjustment.

D.—Standard argand, moves freely along the bar from end to clamp *C*.
L.—Lamp to be measured suspended over the bar.
F F.—Line through sight-box, 67° 30′ above horizontal line *G G*.
G G.—Horizontal line passing through centre of argand and sight-box.
H H.—Centre line of lamp to be measured.
I.—Perpendicular line passing through centre of illuminated screen.
J.—Centre of argand and pointer on carriage of same.
K.—Centre of screen in sight-box on line *G G* and *I I*
S S S.—Screen boards to cut off all but direct rays from sight-box.
T.—Candle-power of argand.
V.—Distance from *J* to *I*.
U.—Candle-power of lamp being measured.
W.—Distance from *K* to *L*.

All the distances having been accurately measured before the test, except that from *J* to *I*, the standard lamp, *D*, was moved along the bar in each reading until the illumination was equal upon the two sides of the screen, precisely as in the usual tests for candle-power with the common sight-box and candle, the difference being solely in the fact that our standard, and not the sight-box, was moved.

The average of ten observations in this way gave us the distance, *V*, from *J* to *I*, in each test. The other distance, *W*, being known already, the candle-power was readily determined.

The results were as follows:

45° Angle Tests, Lungren Lamp, November 5, 1885:—

Candle-power of city gas,	18·60 candles.
Candles per foot of gas,	3·72
TEST NO. 1.	
Gas burned,	16·20 cubic feet.
Candle-power,	197·16
Candles per foot of gas,	12·17
TEST NO. 2.	
Gas burned,	16·65 cubic feet.
Candle-power,	231·78
Candles per foot of gas,	13·09
TEST NO. 3.	
Gas burned,	17·20 cubic feet.
Candle-power,	230·64
Candles per foot,	13·04

(3.) VERTICAL TESTS.

The lamp was suspended over the vertical end of a sight-box, so made that the horizontal rays from our standard argand, and